This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

RESEARCH LIBRARIES
33 05775276 2

A

Arr
3T

XVII.

THE FRENCH COOK.

By Louis Eustache Ude, Ci-devant Cook to Louis XVIII. and the Earl of Sefton, and Steward to his late Royal Highness, the Duke of York. First American from the Eighth London edition. In 1 vol. 12mo. With plates.

XVIII.

LORD BYRON AND HIS CONTEMPORARIES.

By Leigh Hunt. In 8vo.

XIX.

DEATH-BED SCENES,

And Pastoral Conversations. By the late John Warton, D. D. In 1 vol. 8vo.

Contents.—Chap. I. Infidelity.—II. Atheism.—III. Despair. IV. Parental Anger.—V. Baptism.—VI. Penitence.—VII. Proselytism.—VIII. Impatience.—IX. Religious Melancholy.—X. Scepticism.

XX.

SAYINGS AND DOINGS,

Or, SKETCHES FROM LIFE. Third Series.

XXI.

ELIA.

Essays that have appeared under that signature in the London Magazine. First Series. Second Edition.

Contents.—The South Sea House.—Oxford in the Vacation.—Christ's Hospital five and thirty years ago.—The two races of men.—New Year's Eve.—Mrs. Battle's opinion on Whist.—A Chapter on Ears.—All Fools' Day.—A Quaker Meeting.—The old and new Schoolmaster.—Valentine's Day.—Imperfect Sympathies.—Witches and other Night Fears.—My Relations.—Mackery End, in Hertfordshire.—Modern Gallantry.—The Old Benches of the Middle Temple.—Grace before Meat.—My first Play.—Dream Children: a reverie.—Distant Correspondents.—The praise of Chimney-Sweepers.—A compaint of the Decay of Beggars in the Metropolis.—A dissertation upon Roast Pig.—A Bachelor's complaint of the Behaviour of Married People.—On some of the Old Actors.—On the Artificial Comedy of the last century.—On the acting of Munden.

ELIA.—*Second Series.*

Contents.—To Elia.—Rejoicings upon the New Year's coming of Age.—Reflections on the Pillory.—Twelfth Night, or What You Will.—The Old Margate Hoy.—On the inconveniences resulting from being Hanged.—Letter to an Old Gentleman whose education has been neglected.—Old China.—On Burial Societies, and Character of an Undertaker.—Barbara S.——.—Guy Faux—Poor Relations.—A Vision of Horns.—On the Danger of Confounding Moral with Personal Deformity.—On the Melancholy of Tailors.—The Nuns and Ale of Caverswell.—Valentine's Day.—The Child Angel.—Amicus Redivivus.—Blakesmore in H——shire.—Detached Thoughts on Books and Reading.—Captain Jackson.—Confessions of a Drunkard.—The Old Actors.—The Gentle Giantess.—A Character of the late Elia.

CAREY, LEA & CAREY

Will Publish in March,

MR. IRVING'S NEW WORK,

A CHRONICLE

OF

THE CONQUEST OF GRANADA.

In 2 vols. 12mo.

An edition will also be published in 2 vols. 8vo. to match with the 8vo. editions of his preceding works.

Recently published, new Editions of the following works by the same Author.

THE SKETCH BOOK, 2 vols. 12mo.
KNICKERBOCKER'S HISTORY of NEW YORK, 2 vols. 12mo.
BRACEBRIDGE HALL, 2 vols. 12mo.
TALES of a TRAVELLER, 2 vols. 12mo.

They will shortly Publish—

ANNE OF GEIERSTEIN,

OR

THE MAIDEN OF THE MIST.

By the Author of Waverley. In 2 vols. 12mo.

THE WISH-TON-WISH.

By the Author of the Spy, Pioneers, Red Rover, &c. In 2 vols. 12mo.

A TOUR IN AMERICA.

By Basil Hall, Captain R. N. In 2 vols. 12mo.

THE PRINCIPLES

AND

PRACTICE OF MEDICINE.

By Samuel Jackson, M. D.

THE PRACTICE OF MEDICINE.

By W. P. Dewees, M. D.

Just Published—

I. THE AMERICAN QUARTERLY REVIEW, No. IX.

CONTENTS.—Egyptian Architecture.—Instructions to Representatives.—Law of Libel.—History.—Restrepo's Columbia.—Howe's Greek Revolution.—Doctrine of Temperaments.—Darby's View of the United States—Irving's Conquest of Granada.—Memoirs of Dr. Parr. *Terms* five dollars per annum.

II. THE AMERICAN JOURNAL OF THE MEDICAL SCIENCES. No. VI. for February, 1829.

Among the Collaborators of this work are Professors Bigelow, Channing, Chapman, Coxe, Davidge, De Butts, Dewees, Dickson, Dudley, Francis, Gibson, Godman, Hare, Henderson, Horner, Hosack, Jackson, Macneven, Mott, Mussey, Physick, Potter, Sewall, Warren, and Worthington; Drs. Daniell, Emerson, Fearn, Griffith, Hays, Hayward, Ives, Jackson, King, Moultrie, Spence, Ware, and Wright.—*Terms* five dollars per annum.

III. AMERICAN ORNITHOLOGY; or NATURAL HISTORY of BIRDS inhabiting the UNITED STATES. By Charles Lucian Bonaparte. Designed as a continuation of Wilson's Ornithology. Vols. I. and II. are already published, and the third volume will appear in April.

⁂ Gentlemen who possess Wilson, and are desirous of rendering the work complete, are informed that the edition of this work is very small, and that but a very limited number of copies remain unsold.

IV. HEBER'S TRAVELS in INDIA. Second American edition. 2 vols. 12mo.

⁂ A few copies of the fine edition, in 2 vols. 8vo. still remain unsold.

"It forms a monument of talent, sufficient, singly and alone, to establish its author in a very high rank of English Literature. It is one of the most delightful books in the language, and will, we cannot doubt, command popularity as extensive and as lasting as any book of travels that has been printed in our time. Certainly, no work of its class that has appeared since Dr. Clarke's can be compared to it for variety of interesting matter, still less for elegance of execution. The style throughout easy, graceful, and nervous, carries with it a charm of freshness and originality not surpassed in any personal memoir with which we are acquainted."—*Qarterly Review*, No. 73.

V. PALESTINE, and OTHER POEMS. By the same Author. In 18mo.

"Bishop Heber's Palestine, and other Poems, place that lamented scholar in the first class of contemporary bards. The biographical sketch prefixed to the compilation, which is original, as such, does credit to the talent and feeling of the author."—*National Gazette.*

VI. ELEMENTS of PHYSICS, or NATURAL PHILOSOPHY, GENERAL and, MEDICAL, Explained independently of TECHNICAL MATHEMATICS. By Neill Arnott, M. D. First American, from the third London Edition, with additions, by Isaac Hays, M. D.

"Of this valuable, or we might say, invaluable work, a second edition has been speedily demanded by the public voice."—*Lit. Gaz.*

VII. A JOURNEY ROUND MY ROOM, from the French of Count Xavier le Maistre.

VIII. TOKEAH; or the WHITE ROSE, a Novel. In 2 vols. 12mo.

IX. CAZENAVE and SCHEDEL on DISEASES of the SKIN. Translated from the French, in 8vo.

X. ELLIS'S MEDICAL FORMULARY. Second edition, with large additions. In 8vo.

XI. LIGHTS and SHADES of ENGLISH LIFE. From the New Monthly Magazine. In 2 vols. 18mo.

XII. THE ANATOMY of DRUNKENNESS. By Robert M'Nish.

XIII. FAIRY LEGENDS and TRADITIONS of the SOUTH of IRELAND. Second series, with plates.

"We know not whether to admire most the curious research, the imagination, or the exquisite and characteristic humour of the tales."—*Lit. Gaz.*

XIV. The ATLANTIC SOUVENIR; a CHRISTMAS and NEW YEAR'S PRESENT, for 1829.

A few copies of those for 1827 and 1828 are still for sale.

XV. TALES of a GRANDFATHER, first and second series. By the Author of Waverley. In 4 vols. 12mo.

XVI. ST. VALENTINE'S DAY; or the FAIR MAID of PERTH. By the same Author. In 2 vols. 12mo.

XVII. NOTIONS of the AMERICANS: Picked up by a TRAVELLING BACHELOR. In 2 vols. 12mo.

XVIII. The RED ROVER. By the Author of the Spy. In 2 vols. 12mo.

New Editions of the following Works by the same Author—

The SPY. 2 vols. 12mo.

The PIONEERS. 2 vols. 12mo.

The PILOT, a Tale of the Sea, 2 vols. 12mo.

LIONEL LINCOLN, or the LEAGUER of BOSTON, 2 vols.
The LAST of the MOHICANS, 2 vols. 12mo.
The PRAIRIE, 2 vols. 12mo.

XIX. DETRACTION DISPLAYED. By Amelia Opie, in 18mo.

XX. SEVEN YEARS of the ITALIAN OPERA. By John Ebers, in 12mo.

"[illegible] Ebers gives the principal features of the place very happily—we breathe quite an opera atmosphere—we even hear the finale of an overture; catch the sounds of the three managerial *coups*—and behold the crimson curtain 'fretted with golden fires,' ascend before our eyes—Enter Ebers qui See Loquitur."—*Lit. Gaz.*

XXI. TRAVELS of the DUKE of SAXE WEIMER in the UNITED STATES, in 8vo.

XXII. WALSH'S JOURNEY from CONSTANTINOPLE to ENGLAND, in 12mo.

"This is a very interesting and a popular volume, and it can be fearlessly recommended as one of the most engaging volumes that have lately seen the light."—*Monthly Review.*

XXIII. FRANKLIN'S SECOND EXPEDITION to the ARCTIC OCEAN, in 8vo.

XXIV. A MARRIAGE in HIGH LIFE. Edited by the Author of Flirtation, in 12mo.

"The present tale is evidently the production of a lady. Its subject is peculiar and delicate, and it is surprising to observe the nice tact with which the author has steered her way through the dangerous path before her."—*Lond. Lit. Gaz.*

XXV. SERMONS. By the Author of Waverley, 12mo.

XXVI. OMNIPRESENCE of the DEITY. By Robert Montgomery.

⁂ Of this work, seven editions were printed in the course of a few months in England.

"It is indeed a magnificent and sublime composition—in the very highest class of English and sacred poesy."—*Lit. Gaz.*

"We wish particularly to direct attention to the pure, religious, and devotional principle which animates the poem, and which will make it a favourite with a very numerous class of readers of the best kind."—*Ibid.*

XXVII. ELIA. Essays published under that name in the London Magazine, in 2 vols.

XXVIII. BROUGHAM'S SPEECH on the PRESENT STATE of ENGLISH LAW. In 8vo.

XXIX. HUTIN'S MANUAL of PHYSIOLOGY. In 12mo.

XXX. SAYINGS and DOINGS, or SKETCHES from LIFE. Third series. In 12mo.

"Cousin William is, perhaps, the highest effort of the author's deservedly popular pen; and no greater encomium need be bestowed."—*Lit. Gaz.*

XXXI. ANECDOTES of the COURT of NAPOLEON. By M. De Bausset, Prefect of the Palace. In 8vo.

"The anecdotes of the imperial court are very garrulous and amusing."—*New Monthly Magazine.*

XXXII. LORD BYRON and some of his CONTEMPORARIES. By Leigh Hunt. In 8vo.

"Mr. Leigh Hunt, however, is not one of these dishonest chroniclers. His position with regard to Lord Byron, and the long and intimate habits of intercourse with him which he enjoyed, enabled him to contemplate the noble poet's character, in all its darkness and brightness. Gifted, too, like the subject of his memoir, with very remarkable talents, he is much more to be relied on, both in his choice of points of view, and his manner of handling his subject. He is not likely to spoil a bon mot, an epigram, or a conversation; and while he can seize all that was really piquant about his lordship, he is infinitely above retailing the low gossip and garbage, which some Memoir writers have done, in the true spirit of a waiting maid or lacquey."—*New Monthly Magazine.*

XXXIII. WHIMS and ODDITIES, in Prose and Verse, with forty original designs. By Thomas Hood.

XXXIV. DEATH-BED SCENES and PASTORAL CONVERSATIONS. By the late John Wharton, D. D. In 8vo.

Contents.—Chap. I. Infidelity.—II. Atheism.—III. Despair.—IV. Parental Anger.—V. Baptism.—VI. Penitence.—VII. Proselytism.—VIII. Impatience.—IX. Religious Melancholy.—X. Scepticism.

XXXV. UDE'S FRENCH COOK. First American from the Seventh London Edition.

"Mr. Ude is, beyond competition, the most learned of cooks—even of French cooks."—*Lit. Gaz.*

XXXVI. HUMOURS of EUTOPIA, a Novel. 2 vols. 12mo.

XXXVII. PHILOSOPHY in SPORT made SCIENCE in EARNEST. In 2 vols. 18mo.

XXXVIII. MARTINET'S MANUAL of PATHOLOGY. In 18mo.

XXXIX. DEWEES on the DISEASES of CHILDREN. Second edition. In 8vo.

The objects of this work are, 1st, to teach those who have the charge of children, either as parent or guardian, the most approved methods of securing and improving their physical powers. This is attempted by pointing out the duties which the parent or the guardian owes for this purpose, to this interesting, but helpless class of beings, and the manner by which their duties shall be fulfilled. And 2d, to render available a long experience to these objects of our affections, when they become diseased. In attempting this, the author has avoided as much as was possible, "technicality;" and has given, if he does not flatter himself too much, to each disease, of which he treats, its appropriate and designating characters, with a fidelity that will prevent any two being confounded, together with the best mode of teaching them, that either his own experience or that of others has suggested.

XL. DEWEES on the DISEASES of FEMALES. Second edition, with additions. In 8vo.

XLI. DEWEES'S SYSTEM of MIDWIFERY. Third edition, with additions.

XLII. CHAPMAN'S THERAPEUTICS and MATERIA MEDICA. Fifth edition, with additions.

XLIII. COXE'S AMERICAN DISPENSATORY. Seventh edition, with additions.

XLIV. EVANS'S MILLWRIGHT and MILLER'S GUIDE. New edition, with additions. By Dr. T. P. Jones.

XLV. JOHNSON on DERANGEMENTS of the LIVER, INTERNAL ORGANS, and NERVOUS SYSTEM.

XLVI. NICHOLSON'S OPERATIVE MECHANIC and PRACTICAL MACHINIST. In 8vo. With one hundred plates.

XLVII. STRICKLAND'S REPORTS upon the CANALS, RAIL-ROADS, and other PUBLIC WORKS of GREAT BRITAIN. In folio, with plates.

XLVIII. ODES on CASH, CORN, CATHOLICS, and OTHER MATTERS. By Thomas Moore.

XLIX. GIBSON'S PRINCIPLES and PRACTICE of SURGERY. Second Edition, with additions. In 2 vols. 8vo.

L. WISTAR'S ANATOMY. Fourth Edition, with Additions. By W. E. Horner, 2 vols. 8vo.

LI. BROUSSAIS'S PHYSIOLOGY applied to PATHOLOGY. Translated by Drs. Bell and La Roche. Second Edition, with additions.

LII. LAVOISNE'S UNIVERSAL, HISTORICAL, GEOGRAPHICAL and CHRONOLOGICAL ATLAS. Folio; containing 71 maps.

LIII. HISTORICAL, GEOGRAPHICAL, and STATISTICAL AMERICAN ATLAS. Folio.

LIV. VIVIAN GREY. 3 vols. 12mo.

"We hail the author as a master in his art: and we may venture to appeal to the work he has produced as at once a prognostic and accomplishment of original invention, that rare faculty in the genius of this age."

LV. KEPPEL'S TRAVELS from INDIA to ENGLAND. In 8vo.

LVI. INTERNAL NAVIGATION of the UNITED STATES, NATURAL and ARTIFICIAL. In 8vo. with maps.

LVII. MEMOIRS of the HISTORICAL SOCIETY of PENNSYLVANIA. In 3 vols. 8vo.

ELEMENTS

OF

PHYSICS,

OR

NATURAL PHILOSOPHY,

GENERAL AND MEDICAL,

EXPLAINED INDEPENDENTLY OF

TECHNICAL MATHEMATICS,

AND CONTAINING

NEW DISQUISITIONS AND PRACTICAL SUGGESTIONS.

BY NEIL ARNOTT, M. D.,

OF THE ROYAL COLLEGE OF PHYSICIANS.

FIRST AMERICAN FROM THE THIRD LONDON EDITION,

WITH ADDITIONS,

BY ISAAC HAYS, A. M., M. D., &c.

PHILADELPHIA:
CAREY, LEA & CAREY—CHESNUT STREET.
1829.

-15352-

ASTOR LIBRARY
APR
4
1893
NEW YORK

EASTERN DISTRICT OF PENNSYLVANIA TO WIT:

L. S.

BE IT REMEMBERED, that on the twenty-eighth day of January, in the fifty-third year of the Independence, of the United States of America, in the year of our Lord, one thousand eight hundred and twenty-nine. Carey, Lea & Carey, of the said district, have deposited in this office the title of a book, the right whereof they claim as proprietors, in the words following, to wit:

"Elements of physics, or natural philosophy, general and medical, explained "independently of technical mathematics, and containing new disquisitions "and practical suggestions. By Neil Arnott, M. D., of the royal college of "physicians. First American from the third London edition, with additions, "by Isaac Hays, A. M., M. D., &c.

In conformity to the act of the Congress of the United States, entitled, "An Act for the Encouragement of Learning, by securing the copies of Maps, Charts, and Books, to the authors and proprietors of such copies, during the times therein mentioned." And also to the act, entitled, "An Act supplementary to an Act, entitled "An Act for the Encouragement of Learning, by securing the copies of Maps, Charts, and Books, to the authors and proprietors of such copies during the times therein mentioned," and extending the benefits thereof to the arts of designing, engraving, and etching historical and other prints."

D. CALDWELL,
Clerk of the Eastern District of Pennsylvania

Griggs & Dickinson, Printers,
Whitehall.

PREFACE

TO THE SECOND LONDON EDITION.

ALTHOUGH paradoxical, it is true, that human knowledge, the more it is accumulated and perfected, is also the more easily acquired and recollected. As an instance we may refer to our present knowledge of the celestial motions. These, to our ancestors, appeared so inexplicable, that to observe and analyze them, some of the most gifted individuals devoted their lives—yet when at last contemplated through the records of many centuries, by the penetrating genius of NEWTON, they were found all to range themselves under a few simple expressions easily intelligible and easily remembered by an ordinary mind. Thus, now, not only is the confusion of past times, in regard to astronomy, converted into a scene of beautiful simplicity and harmony, but we are able to predict, with certainty, many of the changes which are to happen in time to come. Facts of this kind make it appear, that the progress which is still to be looked for in the human sciences, instead of threatening men who require a good education with additional labour, promises to convert their necessary labour almost into amusement,—amusement, however, which will lead to the most important results.

The author has thought it necessary to make this observation to meet what has been stated by not a few against his present volume, namely, that it is so simple, or easily understood, that he must have left untouched many of the important principles of natural philosphy, lest the study of them should prove too difficult for the generality of his readers. Now the fact is, that he has not only included all the general truths belonging to the department of Physics, but has introduced many matters which are not usually found in treatises on the subject:—what he has avoided are matters of inferior, or at least of limited interest. He has, however, availed himself of a circumstance, either not known or not adverted to by former writers, *viz.* that which may be called the *mathematics of common sense or experience,* and which may be expressed in ordinary language—as distinguished from *technical mathematics,* which has its peculiar language, is perfectly sufficient for the explanation of all the great laws of nature. By attending to this truth, and aiming at extreme simplicity of arrangement, he has avoided that abstruse phraseology which is so generally repulsive, and he hopes he has facilitated, to many gifted individuals, who would otherwise have been deterred by the idea of difficulty, the study of that one among the four great departments of human science, which, after the department of mind, is the most pleasing in its nature, has attained the highest degree of perfection, is the most fruitful of valuable applications, and when fairly understood in its relation to the others, establishes a lucid order through the whole of the intellectual acquirements.

Astronomy, which is the instance chosen above, is only one of innumerable subjects, which, when imperfectly understood, appear obscure and difficult, but when more fully investigated, become simplicity itself. As an example from the studies of medical men may be mentioned the question of the movement of the blood in the veins, which has lately been discussed in medical societies and reviews with considerable earnestness. In this question, the appeal is necessarily made to the laws of Natural Philosophy, which govern the phenomenon; but because the study of these has been little cultivated by the faculty, more time has been absorbed in futile disputation and experiment than would have sufficed for acquiring a competent knowledge of the whole body of Physics:—now the single section of Physics, which bears on the point if understood in a moderate degree, would have caused all the difficulties at once to vanish. The circulation of the blood, again, is but one of numerous and scarcely less important subjects in the medical art to which Natural Philosophy is the easy and only key.

These last reflections are intended as a reply to a second remark which has been made in some quarters with respect to the present volume, *viz.* that its subject is not of primary importance in medical education. Although no one who had advanced beyond the mere threshold of the study, could have held this opinion, the author finds it necessary to advert to it. His labour in preparing the present volume will have been vain, if by it he prove not to his readers that the magnificent fabric of human knowledge has Physics or Natural Philosophy for its foundation, Chemistry for the second department, resting on the first, Physiology or the doctrine of organic Life, for the third resting on the other two, and fully intelligible only to the mind familiar with the others; while the science of mind crowns the whole.

The Author had hoped to be able to publish in the course of this autumn the remaining portion of his Elements of Physics, but the early call for this second edition has prevented him. As the part in question, however, has long been written, there is nothing required in regard to it but what he thinks his leisure will permit him soon to accomplish.

The Author might be accounted insensible to the approbation of his own profession and of society in general, if he allowed the present occasion to pass without alluding to the reception which his book has met. Gratifying indeed has it been to him, and encouraging to the completion of his task. With the desire of making the present volume as worthy as he could make it, of the approval of those into whose hands it may fall, he has carefully revised it, but as he had previously well considered the subjects, he has found nothing beyond verbal inaccuracies to correct. He has however been able to simplify some of his illustrations, and has here and there added new matter. Whatever of this is of a nature to appear complete in a detached form will be printed separately for the accommodation of those who have so recently procured the first edition.

It has been mentioned as a fault in the former edition, that no separate enumeration any where appeared of what might be considered novelties in the work. Now many of these are rather in method, condensation, illustration, &c., than in particular subjects. The following however may be examined as insulated specimens of new disquisition or suggestion:

Theory of the Spinning-Top .... Page 91
Peculiar Pulley 180
Distorted Spine 210
Swimming and Diving 272, 292
Transference of Heat in Liquids, Warm Bath, Brewing Refrigeratories, &c. 279
Pneumatic Tractor 301, 522
Extensive Cupping 313
Distilling and Evaporating 327
Regulation of Temperature in Apartments for Consumptive Patients 361
Water-Wheels for Ships 382
Self-Steering Ship 393
Musical Recorder 415
Musical Glasses 417
Circulation of Blood: in the Arteries 436
———— in the Capillaries 442
———— in the Veins 446
The pulse 460
Bath of strong Pressure 474
Artificial Respiration 482

Analysis of Articulate Speech and Treatment of Stammering 492
Substitutes for Stomach-Pump, &c. 505
Various Means of treating Strictures in the Canals of the Animal Body 513
Means of Treatment for Stone 519

30th Nov. 1827.

ADVERTISEMENT

TO THE

THIRD LONDON EDITION.

1. The present volume will be complete for non-professional readers when the last few leaves, from page 511 to page 526 inclusive, are left out. The binder will take directions accordingly.

2. The printing of the concluding part of the work, *viz.* on Optics, Astronomy, &c., which was to have occupied the author's leisure after the publication of the second edition of Part I., has been again delayed a little by the almost immediate call for the third edition of Part I.; but as future editions of this, if required, may now be made without the author's attention, no farther interruption is anticipated.

INTRODUCTION.

To appreciate the importance of PHYSICS or NATURAL PHILOSOPHY, as an object of study to all persons engaged in scientific pursuit, and indeed, in the present day, to all who pretend to a liberal education, we must take a rapid glance at the nature of human knowledge generally, and at its bearings on the existing condition of mankind. We shall therefore have to consider

- *The progressive condition of men contrasted with the stationary condition of inferior animals;*
- *The dependence of the progress on increase of knowledge;*
- *The fact of the progress being more rapid at present than ever;*
- *The mutual dependence of the departments of knowledge;*
- *The importance of Physics as fundamental to the other departments.*

WHILE the inferior races of animals seem to have changed as little in any respect since the beginning of our records, as the trees and herbs of the thickets which give many of them shelter, the condition of man has fluctuated, and, on the whole, progressed in a very remarkable manner. The inferior animals were formed by their Creator such, that within one life or generation, they should attain all the perfection of which their nature was susceptible. Their wants were either immediately provided for—as the clothing of feathers to birds, and of furs to quadrupeds; or were so few and simple, that the supply was easy to very limited powers—except in a few cases, where considerable art was required, as by the bee in making its honey-cell, or by the bird in constructing its beautiful nest, and there, a peculiar aptitude or instinct was bestowed. Thus a crocodile which issues from its egg in the warm sand, and never sees its parent, becomes as perfect and knowing as any crocodile that has lived before, or that will appear after it.—But how different from this is the story of man! He comes into the world the most helpless of living beings, long to continue so; and if deserted by parents at an early age, so that he can learn only what the experience of one life may teach him,—as to a few individuals has happened who yet have attained maturity in woods and deserts,—he grows up in some respects inferior to the nobler brutes. Now as regards many regions of the earth, history exhibits the early human inhabitants in states of ignorance and barbarism, approaching to this lowest possible grade, and which civilized men shudder to contemplate. But these countries, occupied formerly by straggling hordes of miserable savages, who could scarcely defend themselves against the wild beasts that shared the woods with them, and the inclemencies of the weather, and the consequences of want and fatigue, and who to each other were often more dangerous than any wild beasts, unceasingly warring among themselves, and destroying each other with every species of savage, and even cannibal cruelty —countries so occupied formerly, are now become the abodes of myriads of peaceful, civilized, and friendly men, where the desert and impenetrable forest are changed into cultivated fields, rich gardens, and magnificent cities.

It is the strong intellect of man, operating with the faculty of language as a means, which has gradually worked this wonderful change. By language fathers have communicated their gathered experience and reflections to their children, and these to succeeding children, with new accumulation; and when, after many generations, the precious store had grown until simple memory could retain no more, the arts of writing, and then of printing, arose, making language visible and permanent, and enlarging illimitably the repositories of knowledge. Language thus, at the present moment of the world's existence, may be said to bind the whole human race of uncounted millions into one gigantic rational being, whose memory reaches to the beginnings of written records, and retains imperishably the events that have occurred; whose judgment, analyzing the treasures of memory, has discovered many of the sublime and unchanging laws of nature, and has built on them all the arts of life, and through them, piercing far into futurity, sees clearly events that are to come; and whose eyes and ears and observant mind are at this moment, in every corner of the earth, watching and recording new phenomena, for the purpose of still better comprehending the magnificence and beautiful order of creation, and of more worthily adoring its beneficent Author.

It might be very interesting to show here, in minute detail, how the arts and civilization have progressed in accordance with the gradual increase of man's knowledge of the universe; but it would lead too far from the main subject. We deem it right, however, to make evident to the student the arousing truths, that the progress is not yet at an end; that it has been vastly more rapid in recent times than ever; and that it seems still to proceed with increasing celerity:—and we know not where the Creator has fixed the limits! Although there are thousands of years on the records of the world, our **Bacon**, who first taught the true way to investigate nature, lived but the other day. **Newton** followed him, and illustrated his precepts by the most sublime discoveries which one man has ever made. **Harvey** detected the circulation of the blood only two hundred years ago. **Adam Smith**, **Dr. Black**, and **James Watt** were friends; and the last, whose steam-engines are now changing the relations of empires, may be said to be scarcely cold in his grave. **John Hunter** died not long ago; and **Herschel**'s accounts of newly-discovered planets, and of the sublime structure of the heavens, are in the late numbers of our scientific journals:—illustrious Britons these, who have left worthy successors treading in their steps. On the continent of Europe, during the same period, a corresponding constellation of genius has shone: and LAPLACE was lately the bright star connecting the future with the past.

But there is a change going on in the world, connected closely with the progress of science, yet distinct from it, and more important than half of the scientific discoveries;—it is the *diffusion of existing knowledge* among the mass of mankind. Formerly knowledge was shut up in convents and universities, and in books written in dead languages—or in books which, if in the living languages, were so abstruse and artificial, that only a few persons had access to their meaning: and thus, considering the human race as one great intellectual creature, a small fraction only of its intellect was allowed to come into contact with science, and therefore into activity; which fraction, moreover, was often only half exerted, because sufficient motive was wanting. The progress of science in those times was correspondingly slow, and the evils of general ignorance prevailed. Now, however, the strong barriers which confined the stores of wisdom have been thrown down, and a flood overspreads the earth; old establishments are adapting themselves to the spirit of the age; new establishments are arising; the inferior schools are introducing improved systems of instruction; and good books are rendering every man's fire-side a school. From all these causes there is growing up an *enlightened public opinion*, which quickens and directs the progress of every art and science, and through the medium of a free press, although overlooked by many, is now rapidly becoming the governing influence in all the affairs of man. In Great Britain, partly perhaps as a consequence of its insular peculiarity of situation, the progress of enlightened public opinion has been more decided than in any other state. The early consequences were more free political institutions: and these have gradually led to greater and greater improvements, until Britain is become truly the Queen of the Nations. A colony of her children, imbued with her spirit, now occupies a magnificent territory in the new world of Columbus; and although it has been independent as yet for only half a century, it already counts more people than Spain, and will soon be second to no nation on earth. The example of the Anglo-Americans has aided in rendering their western hemisphere the cradle of many other gigantic states, all free and following the like steps. In the still more recently discovered continent of Australasia, which is larger than Europe, and empty of men, colonization is spreading with a rapidity never before witnessed; and that beautiful and rich portion of the earth will also soon be covered with the descendents of free-born and enlightened Englishmen. From thence still onward, they or their institutions will naturally spread over the vast archipelago of the Pacific ocean, a track studded with islands of paradise.—Such, then, is the extraordinary moment of revolution or transit, in which the world at present exists!—And where, we may ask again, has the Creator predestined that the progress shall cease?—Thus far, at least, we know, that he has made our hearts rejoice to see the world filling with happy human beings, and to observe that the increase of the sciences can make the same spot maintain thousands in comfort and godlike elevation of mind, where with ignorance even hundreds had found but a scanty and degrading supply.

The progress of knowledge which has thus led from former barbarism to present civilization, has gone on by certain steps, which it is easy to point out; and which it is very useful to consider, because we thereby discover the nature of human knowledge, and the relations and importance of its different branches; while we obtain great facilities for studying science, and for quickening its farther progress.

The human mind, when originally directed to the almost infinity of objects in the universe around it, must soon have discovered that there were resemblances among them; in other words, that the infinity was only a repetition of a certain number of kinds. Among animals, for instance, were distinguished the sheep, the dog, the horse; among vegetables, the oak, the beech, the pine; among minerals, lime, flint, the metals, and so forth. And the mind must have become aware that by studying carefully an exemplar of each kind, its limited power of memory might acquire a tolerably correct knowledge of the whole. Now as this knowledge enabled persons more easily to obtain what was useful to them, and to avoid what was hurtful, the desire to possess it must have arisen with the first exercise of reason. The labour of ages has at last nearly completed an arrangement of the constituent materials of the universe, under three great classes of MINERALS, VEGETABLES, and ANIMALS; commonly called the *three kingdoms of nature*, and of which the minute description is termed NATURAL HISTORY; and there are museums of natural history now existing which contain a specimen of almost every object included in these classes, so that a student within the limits of an ordinary garden may be said to be able to examine the whole of the material universe.

While men were examining the *forms* and other qualities of the bodies around them, they could not avoid noticing also the *motions* or changes going on among bodies; and here, too, they would soon make the grand discovery, that there were resemblances in the multitude. Self-interest, as in the case of the bodies themselves, having prompted to careful classification, in the present day, as the result of countless observations and experiments made through the series of ages, we are enabled to say, that all the *motions* or *changes*, or *phenomena* (words synonymous here) of the universe, are merely a repetition and mixture of a few simple manners or kinds of change, which are as constant and regular in every case, as where they produce the returns of day and night, and of the seasons. All these phenomena are referrible to four distinct classes, which we call *Physical*, *Chemical*, *Vital*, and *Mental*. The simple expressions which describe them are denominated *General Truth*, *or Laws of Nature*, and as a body of knowledge, they constitute what is called SCIENCE or PHILOSOPHY, in contradistinction to NATURAL HISTORY, already described. Now as man cannot, independently of a supernatural revelation, learn any thing but what respects, 1st. the momentary state, past or present, of himself and the objects around him;

and 2d. the manner in which the states have changed; *Natural History* and *Science*, in the sense now explained, make up the whole sum of his knowledge of nature.

To exemplify the process by which a general truth or law of nature is discovered, we shall take the physical law of *gravity* or *attraction*. 1st. It was observed that bodies in general if raised from the earth, and left unsupported, fell towards it, while flame, smoke, vapours, &c., if left free, ascended away from the earth. It was held, therefore to be a very general law that things had *weight;* but that there were exceptions in such matters as now mentioned, which were in their nature *light* or ascending. 2d. It was discovered that our globe of earth is surrounded by an ocean of air, having nearly fifty miles of altitude or depth, and of which a cubic foot taken near the surface of the earth, weighs about an ounce. It was then perceived that flame, smoke, vapour, &c. rise in the air, only as oil rises in water, *viz.* because lighter than the fluid by which they are surrounded:—it followed therefore, that nothing was known on earth naturally *light*, in the ancient sense of the word. 3d. It was found that bodies floating in water, near to each other, approached and feebly cohered; that any contiguous hanging bodies were drawn towards each other, so as not to hang quite perpendicularly; and that a plummet suspended near a hill was drawn towards the hill, with force only so much less than the whole weight of the plummet, as the hill was smaller than the earth. It was thus proved that weight itself is only an instance of a more general *mutual attraction*, operating between all the constituent elements of this globe; and which explains, besides, the fact of the rotundity of the globe—all the parts being drawn towards a common centre, as also the form of dew-drops, rain drops, globules of mercury, and of many other things; which, still further, is the reason why the distinct particles of which any solid mass, as a stone or piece of metal, is composed, cling together as a mass, but which when overcome by the repulsion of heat, allows the same particles to assume the form of a liquid or air. 4th. And it was farther observed, that all the heavenly bodies are round, and must, therefore, consist of material obeying the same law. And lastly, that these bodies, however distant, attract each other; for that the tides of our ocean rise in obedience to the attraction of the moon, and become *high* or *spring-tides*, when the moon, and sun operate in the same direction. Thus the sublime truth was at last made evident, and by the genius of the immortal Newton, that there is a power of attraction connecting together the bodies of our solar system at least, and probably limited only by the bounds of the universe.

Who but must admire that the human mind should have power to discover, in such variety and apparent opposition of facts, the operation of a single principle! The process of analysing the facts learned by observation and experiment, so as to deduce from them the general circumstance in which they resemble, is called the method of reasoning by *induction;* and such circumstance is termed the truth or law or scientific principle under which the facts are to be classed. Now while this process is that which leads to the highest objects of philosophy, it is also that by which all the common knowledge of the course of nature is obtained by ordinary minds. It is perceived, for instance, directing the conduct of a child who having discovered the quality of sweetness in various fruits, eagerly carries any newly met species to his lips with the expectation that the resemblance will not fail as to taste where it exists as to form and colour. The very simplicity of this process may have been the reason why the powerful mind of Aristotle disdained it as a scientific instrument, and then instead of deducing the laws of nature from accumulated facts, preferred *supposing* what they should be, that is to say, forming *hypotheses*, and would afterwards admit only such facts as squared with his *hypotheses*. This momentous error kept the mind of the human race in darkness and slavery for two thousand years; and it gave way at last only to the exertion of another of the strongest intellects which has graced the world, that of our illustrious Bacon, whose greatest glory is his having corrected it.

Acquaintance with the laws of nature has been very slowly obtained, owing to that complexity of ordinary phenomena, which is produced by several laws operating together, and under great variety of circumstance. With respect to many laws of Chemistry and Life, men seem to be yet a little further advanced, than they were with respect to the physical law of *attraction*, when they knew only that heavy things fell to the earth. But we have learned enough to perceive that the great universe is as simple and harmonious, as it is immense; and that the Creator, instead of interposing separately, or miraculously, in the common sense of the word, to produce every distinct phenomenon, has willed that all should proceed according to a few general laws.—There is nothing in nature so truly miraculous and adorable, as that the endless and beneficent variety of results which we see, should spring from such simple elements. In times of ignorance, men naturally regarded every occurrence which they did not understand, that is to say, which they could not refer to a general law, as arising from a direct interference of supreme power; and and thus for many ages, and among some nations still, eclipses, and earthquakes, and many diseases, particularly those of the mind, and the winds and weather, were or are accounted miraculous. Hence arose among heathens many ceremonies, and sometimes even barbarous sacrifices, for propitiating or appeasing their offended deities, but founded on expectations no more reasonable, than if we should now pray to have the day or the year made shorter, or to have a coming eclipse averted. They had not yet risen to the sublime conception of one God, who said, "Let there be light," and the light was; and who gave to the whole of nature permanent laws, which he allows men to discover for the direction of their conduct in life—laws so unchanging, that we can calculate eclipses backward or forward for thousands of years, without erring by one beat of a pendulum; and as our knowledge of nature advances, can anticipate and explain other events with equal precision. Even the wind and the rain, which in common speech, are the types of uncertainty and change, obey laws as fixed as those of the sun and moon; and already, as regards many parts of the earth, man can foretel them without fear of being belied. He plans his voyages to suit the coming monsoons, and he prepares against the floods of the rainy seasons.

He who understands the laws of nature, even in the degree in which men now know them, has such clear prescience of the future, and of the effects which will arise from certain causes, that, in many instances, he can interpose and control events to answer his private ends. To a certain extent he thus commands nature, and as expressed in the language of Solomon, repeated since by Lord Bacon, his "knowledge is power." Moreover, as all single material objects and states of objects in the universe, are results of antecedent operation of the laws of change, a man who first studies the laws, knows beforehand in great part the objects which in examining nature he will meet with, and thus most remarkably diminishes the labour of studying *natural history*. He seems to learn by intuition. A well-informed man of the present day, may be said to possess, within the boundaries of his mind, the universe in miniature, where he can contemplate at leisure past events and the present and the future. But let him not be misled by the pride of reason, which naturally arises from such considerations. All his calculations are yet founded on an assumption that the course of nature, as understood by him, has not changed, and will not change. Now, although thousands of years give countenance to the assumption, these thousands are less to a past and a coming eternity, than the noon-day hour, which is an animalcule's life, to rolling ages—an animalcule which cannot know the morning, nor the evening, nor spring, nor winter.—Man, it is true, can fortel the change of day, and of season, and the coming of remote eclipses ; but the mountains of the earth are daily crumbling before his eyes by the action of winds, and rains, and other unremitting causes, and the depths of the ocean are in a corresponding degree filling up ; and stars which his forefathers beheld bright in the firmament, are now dim, or have disapeared ;—awful changes, of which his knowledge, founded on short human experience, can tell him neither the beginning nor the end!

The general laws of nature are divisible, as stated above, into, those of, 1st. *Physics*, often called *Natural Philosophy;* 2d. of *Chemistry;* 3d. of *Life*, commonly called *Physiology;* and, 4th. of *Mind.* Now these four classes may be said to form the pyramid of Science, of which Physics is the base, while the others constitute succeeding layers in the order now mentioned; the whole having certain mutual relations and dependencies well figured by the parts of a pyramid. We must describe them more particularly to show these relations.

Physics.—The laws of *Physics* govern every phenomenon of nature in which there is any sensible change of place, being alone concerned in the greater part of all the phenomena, and *regulating* the rest which originate from chemical action, and from the action of life.—The great Physical truths are now reduced to four, and are referred to by the words *atom*, *attraction*, *repulsion*, and *inertia.* It gives an astonishing, but true idea of the nature and importance of methodical *Science*, to be told that a man, who understands these words, *viz.* how the ATOMS of matter by mutual ATTRACTION approach and cling together to form masses, which are solid, liquid, or aeriform, according to the quantity or REPULSION of heat among them, and which owing to their INERTIA or stubbornness, gain and lose motion, in exact proportion to the force of attraction or repulsion acting on them,—understands the greater part of the phenomena of nature; but such is the fact! *Solid* bodies existing in conformity with these truths, exhibit all the phenomena of *Mechanics; Liquids* exhibit those of *Hydrostatics* and *Hydraulics; Airs*, those of *Pneumatics:* and so forth, as seen in the table of heads given below, at page xxiii. And the whole of this volume is merely a list of the most interesting physical phenomena, arranged in classes under these heads.

Chemistry.—Had there been only one kind of substance or matter in the universe, the laws of Physics would have explained all the phenomena; but there are *iron* and *sulphur*, and *charcoal*, and about fifty others, which, to the present state of science, appear essentially distinct. Now these, when taken singly, obey the laws of Physics; but when placed in contact under certain circumstances, they exhibit a new order of phenomena. Iron and sulphur, for instance, brought together and heated, disappear as individuals, and unite into a new yellow metallic mass which in most of its properties is unlike to either:—under other new circumstances, the two substances will again separate, and assume their original forms. Such changes are called *chemical,* (from the Arabic word signifying *to burn,*) but during them the substances are not withdrawn from the influence of the physical laws,—their weight or inertia, for instance, is not altered; and indeed the phenomenon is merely a modification of general *attraction* and *repulsion.* Many chemical changes besides are only the beginnings of purely physical changes, as when the new chemical arrangement produced by heat among the intimate atoms of gunpowder, causes the physical motion of the sudden expansion or explosion. And all the manipulations of Chemistry, as the transferring of gases from vessel to vessel, the weighing of bodies, pounding, grinding, &c., are directed by Physics alone. Chemistry, then, is truly, as figured above, a modification of or superstructure on Physics, and cannot be understood or practised by a person who is ignorant of Physics.—The chief departments of study involving the consideration of Chemical in conjunction with Physical laws, are enumerated in the table below, under the head of CHEMISTRY.

Life.—The most complicated state in which matter exists, is where, under the influence of life, it forms bodies with a curious internal structure of tubes and cavities, in which fluids are moving and producing incessant internal change. These are called *Organized Bodies,* because of the various *organs* which they contain; and they form two remarkable classes, the individuals of one of which are fixed to the soil, and are called *Vegetables;* and of the other, are endowed with power of locomotion, and are called *Animals.* The phenomena of growth, decay, death, sensation, self-motion, and many others belong to life, but from occurring in material structures which subsist in obedience to the laws of physics and chemistry, the life is truly a superstructure on the other two, and cannot be studied independently of them. Indeed the greater part of the phenomena of organic life are merely chemical and physical phenomena modified by an additional principle. The phenomena of life, from thus involving generally the agency of all the sets of laws, are by far the most complex of any; and the discovery or detection of the peculiar *laws of life*, although these are fixed as the laws of physics or chemistry, has been very slow, and is as yet far from being completed. We cannot as yet explain, why the individuals of animal and vegetable classes live only for a limited time; why off-spring inherit peculiarities of health or disease from the parents; why the various species continue distinct, &c. But many powerful minds of the present day, particularly among medical men, whom it chiefly concerns, are directed to the subject, and important results may be looked for. A vast number of facts have now been carefully observed and recorded, and to a certain degree classified; and perhaps some master-genius may soon arise, to show that a very few simple truths connect the whole, as NEWTON showed with respect to the inferior classifications in physics, when he detected the general laws of *inertia* and *gravity*. The Science of *Life* is divided into *animal* and *vegetable Physiology* (*see the table below.*)

Mind.—The most important part of all science, is the knowledge which man has obtained of the laws governing the operations of his own MIND. This department stands eminently distinct from the others, on several accounts. Unlike that of *organic life*, which could not be understood until physics and chemistry had been previously investigated, this attained extraordinary perfection in a very early age, when the others had scarcely begun to exist. In proof of this assertion, we need only refer to the writings of the Greek philosophers. The most brilliant discoveries, however, were reserved for the moderns, as will occur to many readers, on perusing in the table below, the several divisions of the subject, and recollecting the honoured names which are now associated with each. It is truly admirable to see the modern analysis, deducing from a few simple laws of mind all the subordinate de-

3. LIFE.

Vegetable Physiology,
Botany,
Horticulture,
Agriculture,
&c.

Animal Physiology,
Zoology,
Anatomy,
Pathology,
Medicine,
&c.

4. MIND.

Intellect.

Reasoning,
Logic,
Language,
Education,
&c.

Active Powers.

Emotions and Passions,
Justice,
Morals,
Government,
Political Economy,
&c.
Natural Theology,

---

5. SCIENCE OF QUANTITY.

Arithmetic,
Algebra,
Geometry,
&c.

IN the first stage of education, *viz.* during the years of childhood, the learning acquired is necessarily of the most mixed kind, and is determined by what is called accident; but from the mutual dependence of the different departments of science, as explained in the preceding paragraphs, it follows that, with a view to complete erudition, the order exhibited in "The Table," is that in which they should be studied, so as to prevent repetitions and anticipations, and to diminish as much as possible the labour of acquirement.

Every man may be said to begin his education, or acquisition of knowledge, on the day of his birth. Certain objects, repeatedly presented to the infant, are after a time recognized and distinguished. The number of objects thus known gradually increases, and from the constitution of the human mind. they are soon associated in the recollection, according to their resemblances, or obvious relations. Thus sweetmeats, toys, articles of dress, &c. soon form distinct classes in the memory and conceptions. At a later age, but still very early, the child distinguishes readily between a stone or *mineral* mass, a *vegetable*, and an *animal;* and thus his mind has already noted the three classes of natural bodies, and has acquired a certain degree of acquaintance with *Natural History*. He also soon understands the phrases "a falling body," "the force of a moving body," and has therefore a perception of the great physical laws of gravity and inertia. Having seen sugar dissolved in water, and wax melted round the wick of a burning candle, he has learned some phenomena of Chemistry. And having observed the conduct of the domestic animals, and of the persons about him, he has begun his acquaintance with Physiology and the Science of Mind. Lastly, when he has learned to count his fingers and his sugar-plums, and to judge of the fairness of the division of a cake between himself and his brothers, he has advanced into Arithmetic and Geometry. Thus within a year or two, a child of common sense has made a degree of progress in all the great departments of human science; and in addition has learned to name objects, and to express feelings, by the arbitrary sounds of language. Such, then, are the beginnings or foundations of knowledge, on which future years of experience, or methodical education, must rear the structure of the more considerable attainments which befit the various conditions of men in a civilized community.

The most complete education as regards mind, can only consist in an acquaintance with *Natural History* and *Science*, and with the signs of ideas, *viz. language*, in one or more of its idioms, and the *visible signs* of letters, ciphers, &c. for representing words. As regards the body, it consists in the formation of various habits of muscular action, as in gymnastic exercises, dencing, riding, in performance on musical instruments, games of address, drawing and painting, use of fire-arms, and other exercises of utility or amusement. By reviewing a table of such matters, each man may see at once what he can know, and what it may suit his particular condition to study.

From the preceding pages, it appears that the *Science of Nature* may be considered as a continuous and closely connected system or history, which, to be clearly understood, must be studied according to the natural order of its parts, just as any common history must be read in the natural order of its paragraphs. But so little has this truth been known, or at least, acted upon in general, that perhaps no other human plans formed with one object, have been so dissimilar and inconsistent as the common plans of education. The greater part of the deviations from the arrangement sketched above, must appear so obviously errors, to any person who has at all investigated the subject, that it is unnecessary here to speak of them particularly; but we must notice the important questions as to whether *Mathematics* and *Logic* should come at the beginning or termination of a course of scientific study.

Mathematics are at present generally made the beginning of the study, and the reason assigned is, that scarcely any object in Physics, Chemistry, or Organic Life, can be described without referring to *quantity* or *proportion*, and therefore, without using mathematical terms. Now this is true; but it is equally true, that the mathematical knowledge, acquired by every individual in the common experience of childhood and early youth, in conjunction with the commencements of Physics, Chemistry, and Life, as already explained, is sufficient to enable students to understand all the great laws of nature,—nearly as the knowledge of language obtained at the same time is sufficient, without any study of abstract grammar, to enable him to converse on all common subjects. There are few persons in civilized society so ignorant, as not to know that a square has four equal sides, and four equal corners or angles; or that every point in the circumference of a circle is at the same distance from the centre. Now so much of unity, simplicity, and harmony, is there in the universe, that such simple truths as these are what give exact cognizance of the most important circumstances in the phenomena and states of nature. And indeed as the science of quantity, in its highest flights, is merely comparison of the various simple standards, described at page xxiv, with each other, or of other forms and quantities with them, and as the standards are now familiar to all men living in civilized society, from types or examples being constantly under view, almost every person arrived at years of discretion knows them well, and therefore, is really acquainted with the great fundamental truths of mathematics. When the general laws of nature are once comprehended, and the mind has become familiar with many of the material realities of the universe, the study of the higher mathematics becomes exceedingly inviting, because useful applications of the various truths are immediately perceived: and a good course on mathematics is made to include higher courses on Physics, Chemistry, and Life. But most persons find attention to *pure* or abstract mathematics as irksome as the study of mere vocabulary of a language is to persons not permitted to read the compositions written in the language, and sure of never having to speak, or even think, of half the subjects referred to by the words. This explains why so small a proportion of students, if taught in the common way, become good mathematicians; and why, where pure mathematics are made the avenue to Natural Philosophy, this also is so much neglected.—Although the degree of acquaintance with the *science of measures* which is general among civilized men, is thus sufficient to enable them to comprehend the great laws of nature, yet he who has to apply his knowledge practically, must generally be ready with his arithmetic, and other technical aids,—as in determining, for instance, the proper curve for an arch, or in ascertaining the height of a mountain by a barometer. It is remarkable how much the really simple and attractive science of comparing quantities, has been rendered terrible to the great mass of mankind, by the mystery with which it was surrounded in early times, and which still, under the barbarous names, borrowed from all languages, of *arithmetic, algebra, fluxions, geometry, mathematics,* &c., deters common minds from the study: but men of talent are now smoothing the access, by translating the old technicalities into the common languages, and by mixing with the abstractions the consideration of interesting facts, and already the most useful parts are opened to the easy reach of common understandings and of common leisure. Now, therefore, the truth may be told, that a man's education is very imperfect if the science of measures has been neglected. The mind, when it has once entered on this study by a good route, is in general so charmed by the certainty of the reasonings, and the consciousness of the godlike reach of intellect, which can pursue and catch truths through such intricacies as sometimes present themselves, that it wants no other stimulus to perseverance.

Abstract or technical Logic, which is a branch of the science of mind, has nearly the same relation to that Logic of common-sense which every man of sound mind uses in reasoning or conversing on any subject, as the abstract mathematics have to the mathematics of common experience, of which we have now spoken;—as a preliminary study, therefore, it is of a piece with Abstract Mathematics, and has been commended as such on similarly erroneous grounds.

The notions on education prevalent in the world until recently, have been as erroneous with respect to the comparative importance of different branches of knowledge as with respect to the order of study. Thus at many of our famed schools, and even universities, the attention has been directed almost solely either to *Languages* and *Logic*, or to *Abstract Mathematics;* the preceptors seeming to forget that these objects have no value but in their application to *Physics, Chemistry, Life,* and *Mind.* The reason for bestowing much attention on the Greek and Roman languages was good some centuries ago, because then no book of value existed which was not written in one of these languages; but now the case is completely reversed, for he who learns almost any matter of science from old books is learning error or at the least, knowledge far short of modern erudition. As to the higher mathematics, again, while they merit great honour, as being the instrument by which many useful discoveries have been made, and the conjectures of powerful minds have been confirmed, still a very deep investigation of them is neither possible to the generality of men, nor if it were so, would it be of any utility.* The mode of proceeding to which we have now alluded, is just as if a man, to whom permission were given to enter and possess a magnificent garden, on condition of his procuring a key to open the gate, and measures of all kinds to estimate the riches contained within, should waste his whole life on the road, in polishing one key, or in procuring several of different materials and workmanship, and in preparing a multiplicity of unnecessary measures. This and many similar errors, arise from men not being in general taught to carry in their minds a clear conception of the general field of human knowledge, and thence of the comparative importance of the different subdivisions,—the possession of which conception is perhaps the most valuable single acquirement which the mind can make. He whose view is bounded by the limits of one or two small departments, will probably have very false ideas even of them, but he certainly will, of other parts, and of the whole; so as to be constantly exposed to commit errors hurtful to himself or to others. His mind compared to the well-ordered mind of a properly educated man, is what the crooked and mis-shapen body of the mechanic, confined to certain actions and attitudes, is to the godlike form of the most perfect specimen of human nature.

---

* Our author has not, we think, estimated justly, the value of a knowledge of the dead languages and mathematics. It is not our purpose to enter into a defence of these, but we may remark that, if Greek and Latin were learnt *merely* for the purpose of enabling a person to read the works of science, written in these languages, and mathematics, *only* that one may determine the time of a body descending down the chord of a circle; the greatest rectangle that can be constructed in a given triangle; or the size of a ball, which, being let fall into a conical glass, of a given size, full of water, shall expel the most water possible from the glass; their value would indeed be small. But the object of education is to cultivate and enlarge the mental faculties, and the different branches of study must be estimated as they conduce to that end. In this view, the classics and mathematics, we do not hesitate to assert, hold a very high, if not the highest rank. That they are not equally important to all, and that they are unattainable by many, is true; but they are *essential in a liberal scheme of education.*

AM. ED.

By arranging science according to its natural relations, and therefore so as to avoid repetitions and anticipations, a very complete system might be exhibited in small bulk, *viz.* in five volumes, of which the separate titles would be, 1st *Physics;* 2d. *Chemistry;* 3d *Organic Life,* or *Physiology;* 4th *Mind;* and 5th *Measures* or *Mathematics.* From such works, with less trouble than it now costs to obtain familiarity with one new language, a man might obtain a general acquaintance with science. And such is the close relation of the departments of science with each other, that consummate skill in any one may generally be acquired more easily by first studying the whole in a general way, and then applying particularly to that one, than by fixing the attention from the beginning upon it more exclusively. The study of Anatomy thus becomes very easy to one who has first studied Physics.

The book of five volumes would merit the name of the *Book of Nature.* To have all the perfections of which it is susceptible, it can be looked for only from academies of science or associations of learned men: and even then, it cannot be compiled, as many encyclopedias have been, by each individual taking a distinct part or parts; but by the parts being undertaken conjointly by several persons, so that he who conceives most happily for students may sketch, he who is learned may amplify and complete, he who is correct may purge, he who is tasteful may beautify, &c. After such a book existed, it would not become the object of talented individuals to write a *new book*—which again would necessarily have the imperfections of an individual attempt—but to assist, under the direction of a superintending council, in perfecting the existing work. The composition of the *Book of Nature* might be a worthy object of rivalry even between nations. At present a great part of human labour, and genius, and existence, is wasted for want of such a work. Students, from having no direction, or only that which is faulty, apply to subjects in unnatural order, and therefore neither well understand them at first, nor remember what they read. Many who study various works on the same subject, that the imperfections of one may be corrected or supplied by the others, are confounded by the difference of arrangement met with, and unless they submit to the laborious task of making a complete analysis of all, they seldom have clear notions at last. The vast increase of labour also occasioned by ill-ordered study, discourages and disgusts the greater part of them. If, however, by the care of governments or of universities, the *five volumes* were in existence, and their authoritative character known, a spirited youth, when he began his studies, from seeing at once the limited extent of his task, would enter upon it with that alacrity and confidence which would soon make him accomplish the whole. During the complete review, also, of science and art then made, each individual would be able better to choose the occupation in life suited to his powers and character. The minds of persons generally, becoming thus fully informed in the season of their young vigour, would commence their flight in quest of new discoveries from greater elevations than their predecessors, and might be expected to attain still higher objects. The finest enterprizes of human genius have been planned and commenced, and often accomplished in early youth. There would be this further important consequence, that persons being made so soon to understand the beauty and grandeur of creation, would acquire an elevation of mind, rendering them less likely afterwards to lapse into those sinks of indolence and vice which now engulph so many.

Were such elementary treatises once in existence, they might be maintained complete by a periodical incorporation of new discoveries; and if furnished with correct and copious references, they might form an index to the whole existing mass of knowledge. This *Book of Nature* would be of more value to the world than any other conceivable institution for education, for it would convert the minds of millions into intellectual organs of advancement, and in the crowd there would probably be found in every age, even many as highly endowed by nature, as any that have yet appeared along the continued stream of time.

The increased facility of acquirement here contemplated, would by no means put an end to the distinctions among men of *learned* and *unlearned*, as some might fear. The plan provides for more sound and useful information in the first grades of study, the influence of which would be felt through all; but it leaves the unlimited fields of mathematical research, of Belles-Lettres, of Natural History, &c. as open as ever to the enterprises of leisure, and of peculiar taste. It is true, that the whole intellect of the community would be awakened, and that existing talent would every where be elicited, and employed in what it were most fit to undertake; but this result would be for the general advantage of the state.

In the course of the preceding disquisition, we have seen that *Physics* or *Natural Philosophy*, the subject of the present volume, is fundamental to the other parts, and is therefore that of which the knowledge is the most indispensable. Bacon very truly calls it "the root of the sciences and arts." That its importance has not been marked by the place which it has held in common systems of education, is owing chiefly, 1st. to the misconception already spoken of and refuted, that a knowledge of technical mathematics was a necessary preliminary; and, 2d. to an opinion, also erroneous, that the degree of acquaintance with Physics which all persons acquire by common experience, is sufficient for common purposes:—It is true that the toys of childhood, as the windmill, ball, syphon tube, and a hundred others, furnish so many examples of the laws of Physics, and may well be called a philosophical apparatus; but they give information which is exceedingly vague, and not at all such as is now absolutely requisite in the practice of many of the arts.—If the study of Physics be so easy, then, as now appears, and so important as we shall try still farther to show, there can be no excuse for neglecting it.

The greatest sum of knowledge acquired with the least trouble, is that which comes with the study of the few simple truths of Physics. To the man who understands these, very many phenomena, which to the uninformed appear prodigies, are only beautiful illustrations of his fundamental knowledge,—and this he carries about with him, not as an oppressive weight, but as a charm supporting the weight of other knowledge, and enabling him to add to his valuable store every new fact of consequence which may offer itself. With such a principle of arrangement, his information instead of resembling loose stones or rubbish thrown together in confusion, becomes a noble edifice, of correct proportions and firm contexture, which is acquiring greater strength and consistency, with the experience of every succeeding day. It has been a common prejudice, that persons thus instructed in general laws had their attention too much divided, and could know nothing perfectly. The very reverse, however, is true; for general knowledge renders all particular knowledge more clear and precise. The ignorant man may be said to have charged his hundred hooks of knowledge, to use a rough simile with single objects, while the informed man makes each support a long chain, to which thousands of kindred and useful things are attached. The laws of Philosophy may be compared to keys which give admission to the most delightful gardens that fancy can picture; or to a magic power, which unveils the face of the universe, and discloses endless charms of which ignorance never dreams. The informed man, in the world, may be said to be always surrounded by what is known and friendly to him, while the ignorant man is as one in a land of strangers and enemies. A man may read a thousand volumes of ordinary books as agreeble pastime, leaving vague impressions; but he who studies the *Book of Nature*, converts the great universe into a simple and sublime history, which tells of God, and may worthily occupy his attention to the end of his days.

We have said already, that the laws of Physics govern the great *natural* phenomena of Astronomy, the tides, winds, currents, &c. We will now mention some of the *artificial* purposes to which man's ingenuity has made the same laws subservient. Nearly all that the civil engineer accomplishes, ranges under the head of Physics. Let us take, for instance, the admirable specimens scattered over the British Isles:—the numerous canals for inland traffic; the docks to receive the riches of the world pouring towards us from every quarter; the many harbours offering safe retreat to the storm-driven mariner; the magnificent bridges which every where facilitate intercourse; hills bored through to open roads for commerce by canal boats or carriages, roads which are supported on arches across valleys or above rivers, so that here and there the singular phenomenon is seen of one vessel sailing directly over another; vast tracks of swamp or fen-land drained, and now serving for agriculture; the noble light-house, rearing its head amidst the storm, while the dweller within trims his lamp in safety, and guides his endangered fellow-creature through the perils of the night, &c. &c.

In Holland, great part of the country has been stolen from the sea by the same almost creating power; and now rich cities, and an extended garden, smile, where, as related by Cæsar, were formerly only bogs and a dreary waste.

As a general picture, it is interesting to consider, that in many situations on earth where formerly the rude savage beheld the cataract falling among the rocks, and the wind bending the trees of the forest, and sweeping the clouds along the mountain's brow, or whitening the face of the ocean, and regarded these phenomena with awe or terror, as marking the agency of some great but hidden power which might destroy him;—in the same situations now, his informed son, who works with the laws of nature, can lead the waters of the cataract by sloping channels, to convenient spots, where they are made to turn his mill-wheel, and to do his multifarious work. The rushing winds, also, he makes his servants, by rearing in their course the broad-vaned windmill, which then performs a thousand offices for its master, man. And the breezes which whiten ocean are caught in his expanded sails, and are made to waft their lord and his treasures across the deep for his pleasure or his profit.

In Architecture Physics is also supreme, and has ruled the construction of the temples, pyramids, domes, and palaces which adorn the earth.

In respect to machinery generally, Physics is the guiding light. There are the mighty steam-engine; machines for spinning and weaving, and for moulding other bodies into various shapes, yea, even iron itself, as if it were plastic clay; windmills, and watermills, and wheel carriages: the plough and implements of husbandry; artillery and the furniture of war; the balloon, in which man rides triumphantly above the clouds, and the diving bell, in which he penetrates the secret caverns of the deep; the implements of our intellectual arts, of printing, drawing, painting, sculpture, &c; our musical instruments; our optical and mathematical instruments, and a thousand others.

Besides having all these and other uses, Physics is an important foundation of the healing art. The medical man, indeed, is the engineer pre-eminently; for it is in the animal body that true perfection and the greatest variety of mechachism are found. Where is there, to illustrate *Mechanics*, a system of levers and hinges, and moving parts, like the limbs of an animal body; where such an *hydraulic* apparatus, as in the heart and blood-vessels; such a *pneumatic* apparatus, as in the breathing chest; such *acoustic* instruments as in the ear and larynx; such an optical instrument, as in the eye; in a word, such mechanical variety and perfection, as in the whole of the visible anatomy! All these structures the medical man, of course, should understand, as a watchmaker knows the parts of the machine about which he is employed. The latter, unless he can discover where a pin is loose, or a wheel injured, or a particle of dust adhering, or oil wanting, &c., would ill succeed in repairing an injury; and so also of the ignorant medical man in respect to the human body. Yet will it be believed, that there are medical men who neither understand mechanics, nor hydraulics, nor pneumatics, nor optics, nor acoustics, beyond the merest routine; and that systems of medical education are put forth at this day which do not even mention the department of *Physics!*—That such is the case, furnishes illustration of what is stated in the beginning of this essay; that the sciences and arts are progressive, and that perfect methods of education must arise gradually like all other things of human contrivance. It is within the recollection of persons now living, that political economy has been discovered to be a grand foundation of the art of government, indicating means of security against many national misfortunes common in former times, yea, against even famine and war. And the day is not distant, when the members of the medical profession generally will understand how much the correct knowledge of animal structure and function, and of many remedies, must depend on precise acquaintance of Physics.

Besides the strictly professional matters contained in the medical sections of the present work, there are many others scattered through it which must interest the medical man; such are the subjects of *meteorology, climate, ventilation* and *warming* of dwellings, *specific gravities*, &c. &c. But, indeed, what part of Natural Philosophy is not interesting to a medical man, since the whole is becoming every day more and more a part of a liberal education? In our cities now, and even in an ordinary dwelling-house, a man is surrounded by prodigies of mechanic art; and with his proud reason, is he to use these, as careless of how they are produced, as a horse is careless of how the corn falls into his manger? A general diffusion of knowledge is changing the condition of man and elevating the human character in all ranks of society. Our remote forefathers were generally divided into small states or societies, having few relations of amity with surrounding tribes, and their thoughts and interests were confined very much within their own little territories and rude habits. In succeeding ages, their descendants found themselves belonging to larger communities, as when the English heptarchy was united, but still remote kingdoms and quarters of the world were of no interest to them, and were often totally unknown. Now, however, every one sees himself a member of one vast civilized society, which covers the face of the earth; and no part of the earth is indifferent to him. In England a man of small fortune may cast his looks around him, and say with truth and exultation, "I am lodged in a house that affords me conveniences and comforts which even a king could not command some centuries ago. Ships are crossing the seas in every direction, to bring me what is useful to me from all parts of the earth. In China, men are gathering the tea-leaf for me; in America, they are planting cotton for me; in the West-India islands, they are preparing my sugar and my coffee; in Italy, they are feeding silk-worms for me; in Saxony, they are shearing the sheep to make me clothing; at home, powerful steam-engines are spinning and weaving for me and making cutlery for me, and pumping the mines, that minerals useful to me may be procured. Although my patrimony was small, I have post-coaches running day and night, on all the roads, to carry my correspondence; I have roads, and canals, and bridges, to bear the coal for my winter fire: nay, I have protecting fleets and armies around my happy country, to secure my enjoyments and repose. Then I have editors and printers, who daily send me an account of what is going on throughout the world, among all these people who serve me. And in a corner of my house, I have BOOKS! the miracle of all my possessions, more wonderful than the wishing-cap of the Arabian tales; for they transport me instantly not only to all places, but to all times. By my books I can conjure up before me, to vivid existence, all the great and good men of antiquity; and for my individual satisfaction. I can make them act over again the most renowned of their exploits: the orators declaim for me: the historians recite: the poets sing: and from the equator to the pole, or from the beginning of time until now, by my books, I can be where I please."—This picture is not overcharged, and might be much extended; such being God's goodness and providence, that each individual of the civilized millions that cover the earth, may have nearly the same enjoyments as if he were the single lord of all.

Reverting to the importance of Natural Philosophy as a general study, it may be remarked, that there is no occupation which so much strengthens and quickens the judgment. This praise has usually been bestowed on Mathematics; yet a knowledge of abstract Mathematics existed with all the absurdities of the dark ages; but a familiarity with Natural Philosophy, which comprehends Mathematics, and gives tangible and pleasing illustrations of the abstract truths, seems incompatible with any gross absurdity. A man whose mental faculties have been sharpened by acquaintance with these exact sciences, in their combination, and who has been engaged, therefore in contemplating *real relations*, is more likely to discover truth in other questions, and can better defend himself against sophistry of every kind. We cannot have clearer evidence of this, than in the history of the sciences, since the Baconian method of *reasoning by induction* took place of the visionary *hypotheses* of preceding times. Until then, even powerful minds did not recoil from the most absurd theories on all subjects. Astronomy was mixed with Astrology; Chemistry with Alchemy; Physiology with the singular hypotheses which preceded the discovery of the circulation of the blood; politics with the absurdities of monopolies, prohibitions, balance of trade, &c.—Even religion itself, in various ages and countries, has felt the influence of the state of the public mind as to solid attainments. To a man with the knowledge of nature which we now possess, the fables and licentious abominations of the Greek or Roman theologies are shocking indeed; as are the religions of the God of fire in China, of Vishnoo in India, of Mahomet's imposture and pretended miracles, &c.—But the enlightened Christian minister earnestly recommends the study of nature; first, because from contemplating the beauty of creation discovered by general science, with the wisdom and benevolent design manifest in all its parts, there spring up in every undepraved mind those feelings of delight and gratitude, which constitute the adoration of natural religion, and which form, as shown by many admirable writers on Natural Theology, a fit foundation for the sublime doctrine of immortality: and secondly, because a Revelation must be proved by the miracles which accompanied its establishment; and to enable men to distinguish between miracles and the usual course of nature, a perfect knowledge of that course, or of Natural Philosophy, is essential. All the false religions of antiquity were founded on, and upheld by pretended miracles. As regards the question of immortality, even independently of Revelation, no man who contemplates the order and beauty of the material world, and who sees the hideous deformities of the moral world—where vice so often triumphs, and modest virtue pines and dies—can for a moment believe them to be the work of the same author, unless there be an hereafter or retribution; and feeling that eternal justice requires another state for man, he embraces with delight the cheering promises of Christianity. There have been, however, at various times, even among Christians, sincere, but weak or ill-informed men, who decried the study of the natural sciences, as inimical to true religion—as if God's ever-visible and magnificent revelation of his attributes in the structure of the universe could be at variance with any other revelation!—But such prejudices are quickly passing away. Where considerable knowledge of nature exists, debasing and gloomy superstition must cease. It is not the abject terror of a slave which is inspired by contemplating the majesty and power of our God, as displayed in his works, but a sentiment akin to the tender regard which leads a favoured child to approach with confidence a wise and indulgent parent.

It now only remains for the author to say a few words with respect to the present volume. With his belief that ere long associations of able men will be employed, in the way stated in a former page, to frame and connect the parts of an elementary *Book of Nature*, he adds this to the already existing treatises on Physics, merely with the hope that it may serve usefully for a time, and may then furnish its share of hints for the composition of one more complete. Every person of liberal education must possess such a book, not to be read once and thrown aside as a novel, but to be frequently consulted as a manual. The author was originally led to this undertaking with the view of supplying the desideratum in medical literature, of a treatise on *Medical Physics:* but perceiving, as he proceeded, that the preliminary investigation of *General Physics,* required to suit the work to medical readers, would require to be nearly as extensive as if the work were for general readers, he determined to make it as complete and as extensively useful as possible. He has been encouraged, during his labour, by the belief, that the growing light of science which now exhibits more clearly the natural relations of the different departments of study, as attempted to be pourtrayed in the preceding pages, might enable him to avoid some of the defects of former elementry treatises, and to add some features of novelty and improvement to his own. He thought that an elementary treatise on Natural Philosophy should be characterized—by requiring in the reader no previous information, but a knowledge of the language in which it is written, and the commonest experience of the world; by having an arrangement of the subjects, as scientific or methodical as in a strictly mathematical treatise, yet without using a single term of technical mathematics; by the general principles being illustrated in all cases, by bringing before the reader rather interesting natural phenomena, than artificial experiments and dry abstract reasonings; by containing nothing of so little interest as to be readily forgotten; by being calculated for general readers, and not for those of one profession or class; by embracing such an account of recent improvements, as to foster the spirit which leads to further study and advancement, &c.—In composing the *general* chapters of the work, the author, as far as his ability and leisure would permit, has been guided by these considerations. The sections on *Animal Physics* were, of course, written for medical men; and a great service will be rendered by the work, if it only awakens them to a just sense of the importance of Physics, as one of the foundations of their art. But, even for general readers, there are few parts of these sections which the author would exclude. There is nothing more admirable in nature than the structure and functions of the human body, and there are many reasons why no liberal mind should be careless of the study. The details here are not more anatomical, than the illustrations from the animal economy contained in the common treatises on *Natural Theology*.—From the attempt in this work, to compress into the smallest possible space the greatest possible sum of scientific information, few historical details have been admitted, whether relating to the distinguished men who have benefited the world as authors or inventors, or to the history of the progress of science: such details form an interesting, but distinct branch of study. With the concluding part of the work a list will be given of the best authors who have treated on the various subjects.

The author must not conclude without observing, that no treatise on Natural Philosophy can save, to a person desiring full information on the subject, the necessity of attendance on experimental lectures or demonstrations. Things that are seen, and felt, and heard, that is, which operate on the external senses, leave on the memory much stronger, and more correct impressions, than where the conceptions are produced merely by verbal description, however vivid. And no man has ever been remarkable for his knowledge of Physics, Chemistry, or Physiology, who has not had *practical familiarity* with the objects. With reference to this familiarity, persons who take a philanthropic interest in the affairs of the world, must observe with much pleasure, the now daily increasing facilities of acquiring useful knowledge, afforded by the scientific institutions formed and forming, not only through this kingdom, but through most civilized nations.

Those of the readers of this work who know the manner of a medical man's life, will not be disappointed if they miss here the minute accuracy and polish found in the productions of more leisurely writers; but amidst the interruptions and

anxieties inseparable from the author's employments, he hopes, that any defects which exist are not mixed with considerable errors. He would feel greater solicitude, as to the reception of his work, if he did not know that the subjects embraced in it are so exceedingly interesting in themselves, that when treated with ordinary clearness and precision, they never fail to please.

1st *March* 1827.

ELEMENTS

OF

NATURAL PHILOSOPHY.

SYNOPSIS.

We may admire that a varied edifice, or even a magnificent city, can be constructed of stone from one quarry; yet far surpassing this, it is found that the inconceivably more varied and magnificent fabric of the universe, with all its orders of phenomena, is of elements but a little more complex.

The four words, *atom*, *attraction*, *repulsion*, *inertia*, point to four general truths, which explain the greater part of the phenomena of nature. Because so general they are called *physical* truths, from the Greek word signifying *nature;* an appellation, distinguishing them from *chemical* truths, which regard particular substances, and from *vital* truths, which have relation only to living bodies. Even in the cases where a chemical or vital influence operates, it modifies, but does not destroy, the physical influence. By fixing the attention then on these *four fundamental truths*, the student obtains, as it were, so many keys to unlock, and lights to illuminate the secrets and treasures of nature.

1st. Atom (a Greek word signifying *that which cannot be further divided*) means an exceedingly minute resisting particle. The visible universe is built up of such particles, held together in masses by an influence called

2d. Attraction, which word implies that atoms, whether separate or already joined into masses, tend towards all other atoms or masses, with force proportioned to their proximity:—

trations afforded by the animal economy, constituting—ANIMAL AND MEDICAL PHYSICS.

As no man can well understand a subject of which he does not carry a distinct outline in his mind, it is recommended to the reader of this volume to study the general *synopsis* and the *analyses* placed at the heads of the *chapters* and *sections*, until the memory be strongly impressed with them. The *synopsis* gives a general view of the subject, like what a traveller obtains of a new country from a lofty central peak commanding the whole. The *anlysis* gives a view of one division, like what the traveller has of a portion of the country from a lower summit; and the "*heads*" placed thus between inverted commas may be figured as directing attention to single valleys or fields, in the wide and beautiful domain of nature.

PART I.

THE FOUR FUNDAMENTAL TRUTHS MINUTELY EXAMINED AND USED TO EXPLAIN GENERALLY, FIRST, THE NATURE OR CONSTITUTION OF THE MATERIAL MASSES WHICH COMPOSE THE UNIVERSE, AND SECONDLY, THE MOTIONS OR PHENOMENA GOING ON AMONG THEM.

SECTION I.—THE CONSTITUTION OF MASSES.

ANALYSIS OF THE SECTION.

The visible universe is built up of very minute indestructible ATOMS *called matter, which, by mutual* ATTRACTION, *cohere or cling together in masses of various form and magnitude. The atoms are more or less approximated, according to the quantity or* REPULSION *of heat among them, and hence arise the three remarkable forms in the masses, of solid, liquid, and air, which mutually change into each other with change in the quantity of heat. Certain modifications of attraction and repulsion produce the subordinate peculiarities of crystal, dense, hard, elastic, brittle, malleable, ductile, and tenacious.*

"*Minute Indestructible Atoms.*"*

THE smallest portion of any substance which the human eye can perceive, is still a mass of many ultimate atoms or particles, which may be separated from each other, or newly arranged, but which cannot individually be hurt or destroyed.

---

* The different heads or titles, which appear thus between inverted commas throughout the work, are the successive portions of the *Analyses*, detached for separate consideration. The reader is particularly requested to reperuse the analysis at the several interruptions, that he may have constantly before him that clear view of the general relations among the different parts of the subject, which is essential to a perfect understanding of it.

A particle of powdered marble, hardly visible to the naked eye, still appears to the microscope a block susceptible of indefinite division; and, when it is broken by fit instruments, until the microscope can hardly discover the separate particles of the fine powder, these may be yet farther divided, by dissolving them in an acid: until the whole become absolutely invisible, as part of a transparent liquid.

A small mass of gold may be hammered into thin leaf, or drawn into fine wire, or cut into almost invisible parts, or liquefied in a crucible, or dissolved in acid, or dissipated by intense heat into vapour; yet, after any and all of these changes, the atoms can be collected again to form the original gold, without the slightest diminution or change. And all the substances or elements of which our globe is composed, may thus be cut, torn, bruised, ground, &c. a thousand times, but are always recoverable as perfect as at first.

And, with respect to delicate combinations of these elements, such as exist in animal and vegetable substances, although it be beyond human art, originally to produce, or even closely to imitate many of them, still, in their decomposition and apparent destruction, the accomplished chemist of the present day does not lose a single atom. The coal which burns in his apparatus, until only a little ash remains behind, or the wax-taper which seems to vanish altogether in flame, or the portion of animal flesh, which putrefies, and gradually dries up and disappears—present to us phenomena which are now proved to be only changes of connexion and arrangement among the indestructible ultimate atoms; and the chemist can offer all the elements again, mixed or separate, as desired, for any of the useful purposes to which they are severally applicable. When the funeral piles of the ancients, with their charge of human remains, appeared to be wholly consumed, and left the idea with survivors that no base use could be made, in after time, of what had been the material dwelling of a noble or beloved spirit, the flames had only, as it were, scattered the enduring blocks of which a former edifice had been constructed, but which were soon to serve again in new combinations.

"*Minute.*"

The following are interesting particulars in the arts or in nature, helping the mind to conceive how minute the ultimate atoms of matter must be.

Goldbeaters, by hammering, reduce gold to leaves so thin, that 282,000 must be laid upon each other to produce the thickness of an inch. They are so thin, that if formed into a book, 1,500 would occupy only the space of a single leaf of common paper; and an octavo volume of an inch thick would have about as many pages as the books of a well-stocked ordinary library containing 1,500 volumes of 400 pages in each; yet those leaves are perfect, or without holes, so that one of them laid upon any surface, as in gilding, gives the appearance of solid gold.

Still thinner than this is the coating of gold, upon the silver wire of what is called gold lace, and we are not sure that such coating is of only one atom thick.

Platinum and silver can be drawn into wire much finer than human hair.

A grain of blue vitriol, or carmine, will tinge a gallon of water, so that in every drop the colour may be perceived.

A grain of musk will scent a room for twenty years, and will have lost but little of its weight.

The carrion crow smells its food at a distance of many miles.

The thread of the silk-worm is so small, that many folds are twisted together to form our finest sewing thread; but that of the spider is smaller still, for two drachms of it by weight, would reach from London to Edinburgh, or 400 miles.

In the milt of a cod-fish, or in water in which certain vegetables have been infused, the microscope discovers animalcules, of which many thousands together do not equal in bulk a grain of sand: yet, these have their blood and other subordinate parts like larger animals; and indeed nature, with a singular prodigality, has supplied many of them with organs as complex as those of the whale or elephant. Now the body of an animalcule consists of the same substances, or ultimate atoms, as the body of man himself. In a single pound of matter, it thus appears, there may be more living creatures than of human beings on the face of this globe. What a scene has the microscope laid open to the admiration of the philosophic inquirer!

Water, mercury, sulphur, or, in general, any substance, when sufficiently heated, rises as invisible vapour or gas; in other words, is made to assume the aeriform state. Great heat, therefore, would cause the whole of the material universe to disappear, the most solid bodies becoming as invisible and impalpable as the air we breathe. Utter annihilation would seem but one stage beyond this.

"*Matter.*"

The inconceivable minuteness of ultimate atoms, as shown above, has led some inquirers to doubt whether there really be *matter;* that is to say, whether what we call substance or matter, have existence or not. In answer to this, it has been usual to adduce, besides the proofs of indestructibility already mentioned, and which seem conclusive, the fact, that every kind or portion of matter obstinately occupies some space, to the exclusion of all other matter from that particular space. This occupancy of space, is the simplest and most complete idea which we have of material existence. The awkward word *impenetrability* has been used to express it, with reference of course to the individual atoms. The following are elucidations.

We cannot push one billiard-ball into the substance of another, and then a second, and then a third, and so on; or the material of the universe might be absorbed in a point.

A mass of iron on a support will resist the weight of thousands of pounds laid upon it, and pressing to descendinto its place; and although a very great weight might crush or break it into pieces, still one particle would not be annihilated. In a forcing-pump, or in Bramah's water-press, millions of pounds cannot push the piston down, unless the water below it be allowed to escape.

A weight laid upon bladders full of air, or on the piston-handle of a closed air-pump, is supported in the same manner.

A glass tube, left open at bottom, while the thumb closes the top, if pressed from air into water, is not filled with water, because the air contained in it resists; but if the air be allowed to escape by removing the thumb from the top, the tube is filled immediately to the level of the water around it. In a goblet or basin pushed into water, with the mouth downwards, the entrance of water is resisted for the like reason; and if the goblet be inverted over a floating lighted taper, this will continue to float under it, and to burn in the contained air, however deep in the water it be carried—exhibiting the curious phenomenon of a light below water, and itself an emblem of the living inmate of a diving bell, which is merely a larger goblet with a man instead of a candle.

"*Mutual Attraction*" (*see the analysis, page* 47.)

Any visible mass of matter, then, as of metal, salt, sulphur, &c., we know to be really a collection of dust, or minute atoms, by some cause made to cohere or cling together; yet there are no hooks connecting them, nor nails, nor glue; and the connexion may be broken a thousand times, by processes of nature or art, yet is always ready to take place again; the cause being no more destroyed in any case by interruption, than the weight of a thing is destroyed by frequent lifting from the ground. Now the cause we know not, but we call it *attraction*. The Phenomena of attraction or repulsion, particularly when occurring between bodies at considerable distances from each other, are among the most extraordinary subjects which the human mind has to contemplate; but the manner or laws of the phenomena are now well understood. The general nature and extensive influence of attraction may be judged of from the following facts.

Logs of wood floating in a pond approach each other, and afterwards remain in contact.

The wreck of a ship, in a smooth sea after a storm, is often seen gathered into heaps.

Two bullets or plummets suspended by strings near to each other. are found by the delicate test of the torsion balance (which will be described afterwards) to attract each other, and therefore not to hang quite perpendicularly.

A plummet suspended near the side of a mountain, inclines towards it, in a degree proportioned to its magnitude; as was ascertained by the well-known trials of Dr. Maskelyne near the mountain Skehalion, in Scotland.

And the reason why the plummet in such a case tends much more strongly towards the earth than towards the hill, is only that the earth is larger than the hill.

At New South Wales, which is situated on our globe nearly opposite to England, plummets hang and fall towards the centre of the globe, as they do here; so that they are hanging up and falling towards England, and the people there are standing with their feet towards us,—hence called our antipodes. Weight, therefore, is merely general attraction acting every where.

But it is owing to this general attraction that our earth itself is a globe. All its parts being drawn towards each other, that is towards a common centre, the mass assumes the spherical or rounded form.

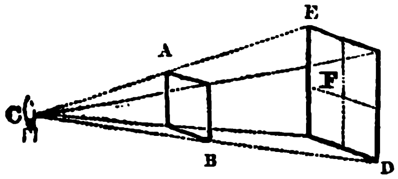
And the moon also is round, and all the planets; the glorious sun too, so much larger than these, is round; proving that all must at one time has been fluid and that all are subject to the same law.

We have also interesting instances of roundness from the same cause in minute masses, as—the particles of a mist or fog floating in air—these, mutually attracting and coalescing into larger drops, and then forming rain—dew drops—water trickling on a duck's wing—the tear dropping from the cheek—drops of laudanum—globules of mercury, like pure silver beads, coalescing when near, and forming larger ones—melted lead allowed to rain down from an elevated sieve, which by cooling as it descends retains the form of its liquid drops, and becomes the spherical shot-lead of the sportsman.

The cause of the extraordinary phenomenon which we call attraction, acts at all distances.—The moon, though 240,000 miles from the earth, by her attraction, raises the water of the ocean under her, and forms what we call the tide.—The sun, still further off, has a similar influence; and when the sun and moon act in the same direction, we have the spring-tides.—The planets, so distant that they appear to us little wandering points in the heaven, yet, by their attraction, affect the motion of our earth in her orbit, quickening it when she is approaching them, retarding it when she is receding.

The *attraction is greater* the nearer the bodies are to each other; as the light of a taper is more intense near to it than at a distance.

A board of a foot square, at a certain distance from a light, just shadows a board of two feet square at double distance; but a board with a side of two feet has four times as much surface as a board with a side of one foot, and therefore light, at double distance, being spread over four times the surface, has only one-fourth of the intensity. This is explained by the *figure*, where C represents the place of a light, AB a square board at a certain distance from it, and ED a shadowed board, in which the side is just twice as long, at double distance—and of which one-fourth, as the corner, FD, is equal to the whole of the smaller square, AB:—thus also a globe of two feet diameter, requires just four times as much paper to cover it as a globe of one foot. Light, and attraction, and indeed every influence from a central point, is found to decrease in the same proportion, *viz.* as the surface or squares which shadow each other increases. The technical expression is "*inversely as the square of the distance.*" It is only one-fourth as strong at double distance; four times as strong at half distance: and in like manner for all distances.



What weighs 1,000 lbs. at the sea-shore, weighs five lbs. less at the top of a mountain of certain height, or raised in a balloon

—as is proved experimentally by a spring balance;—and at the distance of the moon, the weight, or force towards the earth, of 1,000 lbs. is diminished to five ounces, as is proved by astronomical tests.

ATTRACTION has received different names, as it is found acting under different circumstances. The chief distinctions are Gravitation, Cohesion, Capillary and Chemical attractions.

Gravitation is the name given to it, when acting at sensible distances, as in the cases of the moon lifting the tides—the sun and earth attracting each other—a stone falling, &c. Most of the facts enumerated at page 51 belong to this head.

Cohesion is the name given, when it is acting at very short distances, as in keeping the atoms of a mass together.

It might appear at first sight that it cannot be the same cause which draws a piece of iron to the earth with the moderate force called its weight, and which maintains the constituent atoms of the iron in such strong cohesion; but when we recollect that attraction is stronger as the substances are nearer to each other, the difficulty vanishes. Atoms in absolute contact would be a million times, nay, infinitely nearer to each other, than when only a quarter of an inch apart, and therefore when the heat among the atoms of any cohering mass allows them to approach near, they must attract mutually with great force.

Were it not then because the surfaces of bodies are in general so very rough and irregular, that if applied to each other, they can only touch, perhaps, in four or five points out of a million which the surface contains, bodies would be invariably sticking together or cohering by any accidental contact. The effect of artificially smoothing the touching surfaces is seen in the following examples: we may remark, however, that besides irregularity of surface, there is another reason, explained a little further on, which prevents the cohesion.

Similar portions being cut off with a clean knife from two leaden bullets, and the fresh surfaces being brought into contact with a slight turning pressure, the bullets cohere, almost as if they had been originally cast together.

Fresh-cut surfaces of India rubber or caoutchouc cohere in a similar way. We are hence enabled easily to make elastic air-tight tubes, by cutting off the edges of a strip of India rubber and bringing the cut surfaces into contact by winding the strip round any small rod or cylinder, and fixing it there for a time with tape or cord.

Two pieces of perfectly smooth plate glass or marble, laid upon each other, adhere with great force: and indeed so do most well-polished flat surfaces.

Cohesion between a solid and liquid, and between the particles of a liquid among themselves, is seen in the following instances.

A flat piece of glass, balanced at the end of a weighing beam, and then allowed to come into contact with water, adheres to the water, and with much more force than the weight of water remaining upon it, when again forcibly raised. If there were not cohesion or attraction of the water particles among themselves, as well as to the glass, the latter could only be held down by the weight of the water which directly adhered to it.

In pouring water from a mug or bottle lip, the water does not at once fall perpendicularly, but runs down along the inclined outside of the vessel, chiefly in consequence of the attraction between this and the water; hence the difficulty of pouring from a vessel which has not a projecting lip.

The particles of water cohere among themselves in a degree which causes small needles gently laid on the surface to float:— the weight of these is not sufficient to overcome the cohesion of the water surface.

For the same reason many light insects can walk upon the surface of water without being wetted.

It is chiefly the different force of the attraction of cohesion in different liquids that causes their drops or gutts from the lip of a phial to be of different magnitude. Sixty drops of water fill the same measure as 100 drops of laudanum from a lip of the same size.

In a larger mass of liquid, the attraction which would draw the particles into the form of a distinct globe, yields to that which draws them towards the centre of the earth, and therefore the liquid assumes what is called a level surface, that is to say, a surface corresponding with the general surface of the globe of the earth.

Attraction is called *capillary* when it acts between a liquid and a solid, which is tubular or porous.

When an open glass tube is partially immersed in water, the water within it stands above the level of that on the outside; and the difference of level is greater as the tube is less, because, in small tubes, the glass all round being nearer to the raised water, attracts it more powerfully.

Between two plates of glass standing near to each other, the same rising of water will occur; and if they are closer at one perpendicular edge than at the other, the surface of the suspended water will be higher there.

A piece of sponge or a lump of sugar touching water by its lowest corner, soon becomes moistened throughout.

The wick of a lamp lifts the oil to supply the flame, from two to three inches below it.

A mass of cotton thread hanging over the edge of a glass of water will empty it, as a syphon would. A towel will empty a basin of water in the same way.

Dry wedges of wood driven into a circular groove formed round a pillar of stone, on being moistened, will swell so as to rive off the portion from the block. Millstones are thus cut from the rock, in some quarries of Germany.

An immense weight or mass may be raised a little way, by first tightening a dry rope between it and a support, and then wetting the rope:—the moisture imbibed into the substance of the rope by capillary attraction causes it to become shorter.

At one time the small vessels of vegetables were supposed to raise the sap from the roots, by capillary attraction, but this is known now to be chiefly an action of vegetable life.

Attraction has received the name of *chemical attraction*, or *affinity*, when it unites the atoms of two or more distinct substances into one perfect compound.

There are about fifty substances in nature which appear, in the present state of science, distinct from each other, and are therefore called *kinds of matter:* such as the forty metals, sulphur, phosphorus, &c.; but whether these are, in truth, originally and essentially different, or are all only the one, simple primordial matter, modified by circumstances, as yet unknown to us, we cannot at present positively determine.—Diamond and pure black carbon are the same substance, only the atoms are differently arranged; and steel, which in the soft state the graver cuts as it would copper or silver, is exactly the same substance as when, after being tempered by heating and sudden cooling, it has become as hard nearly as diamond itself. Yet these differences are greater than appear between some substances, which we now account essentially distinct.

It is found, however, that the atoms of what we call different substances will not cohere and unite indifferently, as atoms of the same kind do,—there being singular preferences and dislikes among them, if it may be so expressed; and when atoms of two kinds do combine, the resulting compound generally loses all resemblance to either of the elements.—Thus:

Sulphuric acid will unite with copper and form a beautiful translucent blue salt; with iron it will form a green salt; and if a piece of iron be thrown into a solution of the copper salt, the acid will immediately let fall the copper, and take up or dissolve the iron. Sulphuric acid will not unite with or dissolve gold at all.—Quicksilver and sulphur unite in certain proportions and form the paint called vermilion: in other proportions they form the black mass called Ethiops mineral.—Lead, and oxygen gas from the atmosphere, form together what is called red lead, used by painters.—Sea-sand, or flint, and the salt called soda, when heated together, unite and form that most useful substance called glass. Certain proportions of sulphur and of iron combine and produce those beautiful cubes of pyrites, or gold-like metal, which are seen in slate. Chemical attraction operating thus, does not in the slightest degree interfere with general attraction or gravity, for every chemical compound weighs just as much as its elements taken separately.

The history and classification of all these facts, connected with the combinations and analysis of different substances, constitute the science of chemistry—so amusing and so useful. It explains how the fifty kinds of matter which we have mentioned, by combining variously, form the endless diversity of bodies which constitute the mass of our globe. The causes of these various modifications of attraction are yet much hidden from us.

It is a remarkable truth, that when different substances combine in the way now described, the proportions of the ingredients are always uniform, and such as seem to prove that for every atom present, of one substance, there is exactly one, or two, or three, &c. of the other. Therefore, if there be ten atoms of one substance, there are exactly ten, or twenty, &c. of the other; but never an intermediate number, as 13 or 23 to 10, for then a particle of the compound would consist of one atom of the first, and of one and three-tenths, or two and three-tenths, &c. of the second substance, which is absurd, as the atom is indivisible. For instance, a certain number of atoms of quicksilver, which weigh twenty-five grains, combine with a certain number of atoms of sulphur, weighing two grains, and form a black compound called Ethiops mineral, or black sulphuret of mercury; and if a little more of either ingredient be added, it lies as a foreign mixture in the sulphuret of mercury; but if just as much more sulphur be added as at first, so that there may be two atoms of it to every particle of the compound, where there was only one before, a perfect combination of the whole will take place, and a new substance will appear which we call vermilion.—Many elementary substances will only unite in one proportion, so that any two such form only one compound: but others unite in several proportions, and two or more distinct compounds arise out of the same two elements.

It thus appears, that although we do not know the exact number of atoms in a given quantity of any substance ; whether, for instance, a grain of sulphuret of mercury has more or less than a million of them ; still as we know that in that grain there are just as many atoms of sulphur as of mercury, and that the weight of the whole sulphur to that of the whole mercury is as two to twenty-five, we know that the single atoms must have the same relation.

Tables have been formed showing the relative weights of the atoms of different substances ; and the number standing opposite to each substance is called its *equivalent* number—that is to say, the weight of its atom in relation to the weight of some atom chosen as a standard. The *equivalent* of a compound substance depends of course on the equivalents of the ingredients, and on the proportions of the ingredients, as the compound particle contains always a fixed number of constituent atoms.

Besides the simple cases of attraction now explained, there are two curious modifications, called *electrical* and *magnetical* attractions, which, from their peculiarities, are reserved for consideration in a future division of this work.

" *Atoms are more or less close, according to the quantity of heat among them ; hence the forms of solid, fluid, air, &c.*" (*Read the analysis, page* 47.)

Were there only atoms and attraction, as hitherto explained, the whole material of creation would rush into close contact, forming one huge solid mass of stillness and death. But there is also heat or caloric, which counteracts attraction, and singularly modifies the results. It has been described by some, as a most subtile fluid, pervading all things, as water pervades a sponge; others have accounted it merely a vibration among the atoms. The truth is, that we know little more of heat as a cause of repulsion, than of gravity as a cause of attraction: but we can study and classify the phenomena of both most accurately.

When a continued addition of heat is made to any body, it gradually increases the mutual distance of the constituent atoms, or dilates the body. A solid thus is first softened; then melted or fused, that is to say reduced to the state of liquid, as the cohesive attraction is overcome; and lastly, the atoms are repelled to still greater distances, so that the substance is converted into elastic fluid or air. Abstraction of heat from such air causes return of states in the reverse order.

Ice when heated thus becomes water, and the water, when heated farther becomes steam : the steam when cooled again becomes water as before, and the water when cooled becomes ice. Ice, water, and steam, therefore, are three forms or states of the same substance—one of the most common in nature, being the material of the ocean.

Other substances are similarly affected by heat, but as all have different relations to it, some requiring much for liquefaction, and some very little, we have that beautiful variety of solids, liquids, and airs, which make up our external nature.

Dilatation.—A rod of iron, which, when cold, will pass through a certain opening, and will lie lengthwise between two fixed points, when heated, becomes too thick and too long to do either.

For accurate mensuration, therefore, rods or chains used as the measure, must either be at a given temperature, or due allowance must be made for the difference.

The wall of a building had begun to bulge out so as to threaten its stability. No force tried was sufficient to return it to perpendicularity, until the idea occurred of using the contracting force of iron while cooling. The wall was connected with the opposite wall by a number of iron bars, passing through both and having nuts screwed upon their projecting ends, which bars were then heated, one half at a time, by lamps placed under them, and while lengthened in consequence, and projecting beyond the wall, the nuts were screwed close up to the wall, so that on again cooling and contracting, they pulled the wall back to its place.

The iron rim of a coach-wheel, when heated, goes on loosely and easily, and when afterwards cooled it binds the wheel most tightly, giving remarkable firmness and strength,

Iron hoops on masts and on casks are made to bind in a similar manner.

and the compressed air,

The common thermometer for measuring degrees of heat, is a glass bulb filled with mercury or other fluid, and having a narrow tube rising from it, into which the fluid ascends on being expanded by heat, and so marks the degree.

A flaccid bladder of cold air on being heated becomes tense, and in certain cases will burst.

Liquid and Air.—A piece of gold, lead, pitch, ice, sulphur, or of other thing, if sufficiently heated, melts or becomes liquid; each substance, however, requiring a different degree of heat—gold requires 5,000 degrees, lead 600, ice 32, and so forth; and if the heating be afterwards continued, most things at certain higher temperatures suddenly expand again to many times the liquid volume, and become æriform fluids.

The conversion of water into steam is familiarly known to all. One pint of water driven off as steam from the boiler of a low-pressure steam engine, fills a space of nearly 2,000 pints, and raises the piston through this, with a force of many thousands of pounds: it immediately afterwards appears again in the cold condenser, as a pint of water.

Six times as much heat is required to convert a pint of water into steam, as to raise it from an ordinary to a boiling temperature; but the steam, by occupying nearly 2,000 times the space of the water, proves that heat merely produces a repulsion among the particles and by no means fills up the insterstices. The steam rising from boiling water, does not appear hotter to the thermometer than the water itself; and hence it was that Dr. Black, whose genius shed so much light on this part of knowledge, gave to the excess of heat the name of *latent heat.*

The latent heat of common air is made sensible in the *match syringe.* In this, the piston is driven down quickly and strongly, so as to compress very much the air which is underneath it, and the heat then squeezed out of the air, or condensed with it, is sufficient to light a match attached to the bottom of the piston.

Not only are spirits, æthers, oils, &c. convertible, as water is, into aeriform fluid, but also sulphur, phosphorus, mercury, and indeed all the metals and elementary substances;—some of them however, requiring heats of great intensity.

The varieties of form, then, in the bodies on the face of this earth, are accidental, or dependent on the temperature of the earth, and do not mark the permanent nature of the substances.

In the planet Mercury, which is near the sun, resin, tallow, wax, and many vegetable substances deemed by us naturally solid, would all be liquid, as oil is with us; and a certain mixture of tin, zinc, and lead, which with us is solid at common temperatures, but melts in boiling water, would there be always liquid like our quicksilver. Our water, oils, and spirits, would there be in a state of steam or air, and could not be known as liquids at all, except by cooling processes and compression, such as we have lately learned to use for reducing our different airs to the form of liquids.

Again, in the cold planet Herschell, which is nineteen times farther from the sun than is our earth, water, if it exist, can be known only as a rock crystal, which fire would have to melt as it does glass with us: our oils would be as butters or resins, and quicksilver might be hammered, as lead or silver is with us.

On our own earth, near the equator, common sealing-wax will not retain impressions; butter is oil in the day, and a soft solid at night, and tallow candles cannot be used. And near our pole, in winter, the quicksilver from a broken thermometer is solid metal; water must be melted by fire for use: oils are solid, &c.

To judge then of the constitution of nature aright, we must always take extended surveys, and not allow prejudice to mislead us, as in the case of the Eastern potentate, who put a traveller to death for saying that he had visited remote northern countries, where water was sometimes to be seen solid like crystal, and sometimes white and fleecy, like feathers.

The ancients believed that there were just four elements concerned in forming our globe, and all upon it, viz. *earth*, *water*, *air*, and *fire*. What a contrast between former and present knowledge!

Repulsion without sensible Heat.

As we stated in a former paragraph, that besides general attraction, under the names of gravitation, cohesion, capillary, and chemical attraction, there are modifications which have the names of electrical and magnetical attractions; so we have now to remark, that, besides the general repulsion of heat just described, there are peculiarities which we call electrical and magnetical repulsions. Whether these depend altogether on different causes, or are only modifications of effect from the same cause, we cannot yet positively decide.

It is a curious fact connected with the subject, that there seems to be a film of repulsion, so to express it, covering the general surfaces of all bodies, and preventing their meeting in absolute contact, even when they appear to the human eye so to do. Were it not for this, things would be constantly approaching so closely to each other, that they would stick or cohere, in a way to disturb the common operations of nature and art. The following facts illustrate this superficial repulsion, and the means which art uses to overcome it for particular purposes.

Newton found that a ball of glass, or a watchglass, laid upon a flat surface of glass, does not really touch it, and cannot be made to touch it by a force of even 1,000 pounds to the inch.

In like manner, when glass, stone, porcelain, or indeed almost any body is broken, we cannot make the parts cohere again by simply pushing them together in their former position: where a union therefore between separate masses is desired, we are compelled to have recourse to various artifices.

A few cases in which cohesion is easily effected, were enumerated at page 55: the following are other instances of a different kind.

Gold leaf laid upon clean steel, and then forcibly struck by a hammer, coheres to the steel and gilds it permanently.

But iron can be made to cohere to iron, only by making both pieces red hot before hammering, the process is called welding.

Iron and platinum are the only metals that can be welded.

Tin and lead, in sheets, pressed together between the strong rollers of a flatting-mill, cohere.

The other metals require to be melted before the superficial repulsion gives way so as to allow separate quantities to cohere or run into one mass. It is thus, for instance, that gold, silver, lead, &c. are treated.

In many cases the substances are not such as can be melted (wood or marble for instance,) and then it is necessary to use some sort of glue or cement. Cements must have strong attraction for both substances, and, when dry or cool, must be tenacious in themselves; solder, paste, common glue, mortar, &c. are the principal substances of this kind.

"*Certain modifications of Attraction produce the subordinate states, called crystal, porous, dense, &c.*" (*Read the analysis, page* 47.)

It is a remarkakle circumstance, that attraction, in causing the atoms to cohere so as to form solid masses, seems not to act equally all around each atom, but between certain sides or parts of one, and corresponding parts of the adjoining ones; so that when atoms are allowed to cohere according to their natural tendencies, they always assume a certain regular arrangement and form, which we call crystal. Because in this circumstance they seem to resemble magnets, which attract each other only by their poles; the fact has been called the polarity of atoms. It is the cause of several of the peculiarities above enumerated, as elasticity, &c.

"*Crystallization*" is exemplified in the following particulars:

Water beginning to freeze, shoots delicate needles across the surface; these thicken and interweave until the whole mass has become solid, but the crystalline arrangement always remains. In most substances it is remarkably proved, by the forms of the surfaces left, when the mass is broken.

Moisture freezing on the window-pane in winter, exhibits the most beautiful varity of aborescence.

A flake of snow, viewed in the microscope, is seen to be as symmetrically formed as a fern leaf or a swan's feather.

If a piece of copper be thrown into a solution of silver in nitric acid, it is preferred by the acid to the silver, and is dissolved accordingly: the silver in the mean time, during its precipitation or separation, assumes the form of a beautiful shrub or tree, resting on the remaining copper as its root. This appearance is called the *arbor Dianæ*.

Any metal which has been melted, when allowed to cool again, slowly and at rest, becomes solid first on the outside of the mass. If, before the cooling be completed, the remaining liquid be poured from within, a curious internal crystalline structure, like grotto work, is seen. What is called the grain of a metal is the result of this crystallization.

Saltpetre, glauber salt, copperas (to use popular names,) or any other of the many neutral salts, being dissolved in water, and the water being then allowed slowly to evaporate, re-appears in beautiful regular crystals, each salt having its peculiar forms.

All the precious stones are crystals, and can be well cut, only parallel to their natural faces.

The basaltic pillars of the Giant's Causeway in Ireland, and of the Isle of Staffa, which appears like a garden supported on magnificent columns in the midst of the ocean, are natural crystalline arrangements of particles, equalling in regularity and beauty any human work, and so far surpassing in grandeur even the Egyptian pyramids, that superstitious conjecture naturally supposed there had been giant architects.

It would be endless to go on enumerating crystalline masses, for all nature's forms, in the inanimate creation, as well as in most organized bodies, are regular and symmetrical; and what we see of broken continents, and islands, and rocks, and wild alpine scenery, are the effects of subsequent convulsions, which have deranged a primitive and natural order.

Much ingenuity has been employed to account for the specific forms which different bodies assume; but the subject is not yet reduced to a state fitting it to be a part of this elementary study. A familiarity with the various figures, which the exact *science of measures* treats of, is required in the person who expects to pursue it with pleasure or advantage. The facts are extremely curious, and the scientific investigation of them may ultimately give important information respecting the intimate constitution of material nature.

"*Porous.*"—The crossing of the constituent crystalline needles or plates in bodies, causes them to be porous or full of small vacant spaces. In some cases these are visible to the eye, in many more, they are so to the microscope, and in all they are to be proved in some way.

Owing to the porosity arising from the new arrangement of atoms on solidifying, water and a very few other substances become more bulky in the change from the liquid to the solid state. Water then dilates with such force, as to burst the strongest vessels which art can provide, and in winter to split rocks, where it has been retained in their crevices. Freezing water thus curiously produces effects which surpass those of exploding gunpowder. This agency of water contributes to the gradual breaking down of our alpine summits, and the frequent discharge of the destructive fragments into the valleys.

The stone called hydrophane (agate) is opaque, until dipped into water, when it absorbs into its pores one-sixth of its weight of the water, and afterwards gives passage to light.

Into crystallized sugar, and various stones, much water will enter without increasing the bulk.

A kind of sand-stone, suitably shaped, forms an excellent filter or strainer for water.

Pressure will force water through the pores of the most solid gold;—as was seen in the famous Florentine experiment, where a hollow, thick, golden ball, being filled with water and squeezed, to try the compressibility of water, was found to perspire all over.

The examples of porosity in animal and vegetable bodies are, however, the most remarkable.

Bone is a tissue of cells and partitions, as little solid as a heap of empty packing-boxes.

Wood is a congeries of parallel tubes, like bundles of organ pipes.—It has lately been proposed to prepare wood for certain purposes, as for making the great wooden pins or nails used in ship-building, by squeezing it to half its bulk between very strong rollers: it thus becomes nearly as heavy and as strong as metal.

A piece of wood sunk to a great depth in the ocean, and exposed to the pressure there, has its pores filled with water, and becomes nearly as heavy as stone. Thus the boat of a whale-fishing ship, which had been dragged far under water by a whale, on being afterwards drawn up, was supposed to be bringing a piece of rock with it.

A piece of cork in a strong close glass vessel nearly full of water, may be seen floating at the top; but if more water be then forcibly pumped into the vessel, the cork will be squeezed and reduced in size, until at last it becomes heavier than water and sinks. On afterwards allowing water to escape, the cork will resume its bulk and rise. A cork sunk 200 feet under water will never rise again of itself.

A bottle of fresh water, corked and let down thirty or forty feet into the sea, often comes up again with the water saltish, although the cork be still in its place: the explanation being, that the cork, when far down, is so squeezed as to allow the water to pass in or out by its sides, but on rising resumes its former size.

"*Density,*" or the quantity of atoms which exist in a given space, is very different in different substances.

A cubic inch of lead is forty times heavier than the same bulk of cork. Mercury is nearly fourteen times heavier than an equal bulk of water.

The density depends on three circumstances: first, on the size or weight of the individual atoms; secondly, on the degree of porosity just now explained; thirdly, on the proximity of the atoms in the more solid parts which stand between the pores.

From many circumstances it appears, that the atoms even of the most solid bodies are nowhere in actual contact, but are retained in their places by a balance between attraction and repulsion—thus, A body dilates or contracts, according as heat is added to or taken away from it.

A weight placed on any upright rod or pillar, shortens it, and if suspended from the bottom lengthens it,—the rod in both cases returning to its former length when the weight is removed.

When a plank or rod is bent, the atoms on the concave side are for the time approximated, and those on the convex side are drawn more apart.

Tin and copper melted together to form bronze, occupy less space by one-fifteenth than they do when separate: proving that the atoms of the one are partially received into what were vacant spaces in the other. A similar condensation is observed in many other mixtures. A pound of water and a pound of salt, when mixed, form two pounds of brine, but they have then much less bulk than when separate. So also of a pound of sugar dissolved in a pound of water.

Water and liquids generally, resist compression very powerfully, but they yield enough to show that the particles are not in contact. It is found that at 1,000 fathoms down in the sea, the superincumbent water compresses that which is below into bulk by about a hundredth part less than it would have at the surface.

In aeriform masses the atoms are very distant, and hence the masses are more easily compressed. A pint of water on assuming the aeriform state, in which it is called steam, under ordinary pressure, acquires nearly 2,000 times its former bulk. A hundred pints of common air may be compressed into a pint vessel, as in the chamber of an air-gun; and if the pressure be much farther increased, the atoms will at last collapse and form an oily liquid. The heat which was contained in such air, and gave it its form, is squeezed out in this operation, and becomes sensible all around.

From these proofs of the non-contact of the atoms, even in the most solid parts of bodies; from the very great space obviously occupied by pores—the mass often having no more solidity than a heap of empty boxes, of which the apparently solid parts may still be as porous in a second degree, and so on; and from the great readiness with which light passes in all directions through dense bodies, like glass, rock crystal, diamond, &c., it has been argued that there is so exceedingly little of really solid matter, even in the densest mass, that the whole world, if the atoms could be brought into absolute contact, might be compressed into a nutshell. We have as yet no means of determining exactly what relation this idea has to truth.

The *comparative weights of equal bulks* of different bodies are called their *specific gravities.*

In thus comparing bodies it was necessary to choose a standard; and water, as being the most easily procurable at all times and at all places, has been generally adopted. The following are a few examples.

The metal called platinum, the heaviest of known substances, is about twenty-two times as heavy as an equal bulk of water—gold is nineteen times as heavy—mercury thirteen and a half—lead eleven—iron eight and a half—copper eight—common stones about two and a half—woods from a half to one and a half—cork one quarter, &c.

"*Hardness*" is not proportioned, as might be expected, to the density of the different bodies, but to the polarity of the atoms in them, that is, to the force with which the atoms hold their places in some particular arrangement.

Hardness is measured generally by the circumstance of one body being capable of scratching another.—It is worthy of notice, however, that the powder or dust of a softer body will often aid in wearing down or polishing one that is harder.

Gold though soft is four times heavier than the hard diamond; and mercury, which is fluid, is nearly twice as dense as the hardest steel.

Diamond is the hardest of known substances. It cuts or scratches every other body, and is generally polished by means of its own dust.

Glass-cutters use a point of diamond as a glass-knife for dividing and shaping their panes.

Common flint also cuts glass, as is seen in the common scribblings on windows.

It is remarkable, that the preparation of iron, called steel, may either be soft like pure iron, or by being heated and suddenly cooled, in the process called tempering, may become nearly as hard as diamond. The discovery of this fact is perhaps second in importance to few discoveries which man has made; for it has given him all the edge-tools and cutting instruments, by which he now moulds every other substance to his wishes. A savage will work for twelve months, with fire and sharp stones, to fell a great tree and to give it the shape of a canoe; where a modern carpenter, with his tools, could accomplish the object in a day or two.

The project has lately been realized of making engravings on plates of soft steel instead of copper, and afterwards tempering the steel to such hardness that it may be used as a type or die to make its impression, not on paper, but on other plates of soft steel, or of copper; each of which is then equal in value to an original and distinct engraving, by this means the beautiful productions of art, instead of being limited to a comparatively small number of copies and persons, may be multiplied almost to infinity, becoming the chief delight of all.

"*Elasticity*" is present in a mass when the atoms, cohering in a particular arrangement only, yield, however, to a certain extent when force is applied, but move back or regain their natural positions on the disturbing force being withdrawn.

Elastic bodies vary much as to the extent to which they yield without breaking, and as to the degree of perfection with which, after the bending, or displacement of atoms, they regain their former state. India rubber is extensively elastic, for it yields far; but it is not perfectly elastic, for when stretched much or often, it soon becomes permanently elongated. Glass, again, is perfectly elastic, for it will retain no permanent bend: but, unless in very thin plates indeed, or in fine threads, it will not bend far without breaking.

All hard bodies are elastic, as steel, glass, ivory, &c., and many soft ones, as caoutchouc, silk thread, a harp-string, &c. The aeriform bodies are all perfectly elastic, as is rudely seen in a bladder filled with air and squeezed, and they will change volume to a very great extent. Liquids also are perfectly elastic, but to a small extent.

A good steel sword may be bent until its ends meet, and yet when allowed, will return to perfect straightness.

A rod of bad steel, or of other metal, will break in bending, or will retain a bend.

An ivory ball, let fall on a marble slab, rebounds by its perfect elasticity nearly to the height from which it fell, and no mark is left on either. If the slab be wet, it is seen that the ivory had been a good deal flattened at the point of contact, for a considerable circular surface of the slab is found dried by the blow, Billiard-balls scarcely loose even their polish by long wear, although the touching parts yield at every stroke.

A marble chimney-piece long supported by its ends, is found at last to be bent downwards in the middle; and the bend is permanent.

A steel watch-spring, although so often and so much bent, resumes its original form when freed at the end of a century; but occasionally, without evident cause, while in action, it will suddenly break.

Elasticity is a property of bodies of great utility to man, as in his time-pieces, carriage-springs, gun-locks, &c. &c.

> "*Brittleness*" designates that constitution of a body where, with hardness, and elasticity perfect as far as it goes, the cohesion among the atoms is such that a very slight change of position among them is sufficient to produce a rupture. A comparatively slight force, therefore, if sudden, breaks them. It belongs to most very hard bodies.

Glass scratches an iron hammer, proving that it is harder than iron—yet glass is the very type of fragility; yielding to the stroke of soft wood, or indeed of almost any thing.

Steel, when tempered so as to be very hard, becomes brittle also. The steel chisels and tools with which artificers now cut and shape the metals, as they formerly did wood, require of course to be exceedingly hard; but they thus lose in regard to the *extent* of their elasticity and hence are frequently broken. Cast iron, which is much harder than malleable or wrought iron, is very brittle, while soft iron and steel are the toughest things in nature.

" *Malleable,*" or reducible into thin plates or leaves by hammering. This property, in opposition to elasticity and brittleness, belongs to bodies whose atoms cohere equally in whatever relative situations they happen to be, and therefore yield to force, and shift about among each other, almost like the atoms of a fluid, without fracture or change of property.

Gold is remarkably malleable for it may be reduced to leaves of the thinness of 282,000 to the inch. For gold-beaters the metal is first formed into rods, these are afterwards rolled or flattened into ribands, the riband is cut into portions, which are extended by hammering to great breadth and thinness, and which being again divided into portions, are hammered and extended to the thinness described.

Silver, copper, and tin may also be hammered until very thin. Most other metals tear and break before the operation is carried far ; and some, on being struck, break at once, almost like glass.

" *Ductile,*" or susceptible of being drawn into wire. One would almost expect malleability and ductility to belong to the same substances and in the same degrees—but they do not. In ductile substances, as in malleable, the atoms seem to have no more fixed relation of position than in a liquid, but yet they cohere very strongly.

One end of a rod of iron, or other ductile metal, being reduced in size so as to pass through an opening in a plate of steel, is seized by strong nippers on the other side of the plate and the whole rod is drawn through. It is thus reduced, of course, to the size of the opening, and is lengthened in a like proportion. By repeating the operation through smaller holes successively, a wire may at last be obtained of the size of a hair.

Dr. Wollaston's ingenuity produced platinum wire smaller than spider's thread. He drilled a hole in the axis of silver wire, and filled it with small platinum wire. He then reduced the compound piece to the smallest wire possible, and on dissolving the silver from the outside, he exposed to view the beautiful filament of platinum.

The order in which metals may be ranged according to their ductility is, platinum, silver, iron, copper, gold, &c.

Melted glass has great ductility. The workers draw or spin it into threads, by merely attaching a point, pulled out from the mass, to the circumference of a turning-wheel. A uniform thread continues to be drawn out and wound upon the wheel, at the rate of 1,000 yards or more per hour. This glass thread when cut into bunches, resembles beautiful white hair.

"*Pliant.* In bodies distinguished by this title, the cohesion is not destroyed by considerable change of direction among the atoms, but, unlike what happens in a ductile mass, the same atoms always remain together. Pliant things are chiefly animal and vegetable fibres and membranes—silk, bladder, lint, hemp, &c. &c.

"*Tenacity*" means the force of cohesion among the atoms of any mass. It belongs more or less to all solids and even to liquids.

This property varies much in different substances. Iron and its modification called steel possess it in the most remarkable degree.

The following table shows the comparative tenacity, or strength to bear pulling, of different metals and woods. Supposing similar wires or rods of each to be used, and of such a size that the surface of a cross-section would be one-thousandth of a square inch, the weights supported would be nearly as follows :—

METALS.

Cast steel	134 *lbs.*
Best wrought Iron.	70
Cast Iron	19
Copper	19
Platinum	16
Silver	11
Gold	9
Tin	5
Lead	2

WOODS.

Teak	13
Oak	12
Beech	12½
Ash	14
Deal	11

Steel wire will support about 39,000 feet of its own length.

Iron, compared in this way, is five or six times stronger than oak.

Certain animal substances have great tenacity : as—the silkworm's thread, which is our strongest connecting or sewing material, and has such flexibility united with its strength—the ligaments and tendons of the animal body, possessing at once such admirable strength, elasticity, and pliancy : these, when dried, and otherwise prepared, constituted the bow-strings of our remote forefathers—the hair or wool of animals, twisted into threads, and worked into the strong and beautiful textures of the loom—strips of animal intestine, prepared and twisted, forming the cords of harp and violin, and in strength and uniformity rivalling the steel wires of keyed instruments.

The gradual discovery of substances possessed of strong tenacity, and which man could yet easily mould and apply to his purposes, has been of great importance to his progress in the arts of life. The place of the hempen cordage of European navies is still held in China by twisted canes and strips of bamboo ;

and even the hempen cable of Europe, so great an improvement on former usage, is now rapidly giving way to the more complete and commodious security of the iron chain—of which the material to our remote ancestors existed only as useless stone or earth.—And what a magnificent spectacle is it, at the present day, to behold chains of tenacious iron stretched high across a channel of the ocean, as at the Menai Strait between Anglesea and England, and supporting an admirable bridge-road of safety, along which crowded processions may pour, regardless of the deep below, or of the storm; while ships there, with sails full-spread, pursue their course, unmolesting and unmolested!

APPENDIX

TO PART I.—SECTION I.

BY THE AMERICAN EDITOR.

If the reader has studied the preceding section with attention he is prepared to understand the following *propositions*.

Prop. 1.—Matter is endowed with properties.

Prop. 2.—The properties of matter are distinguishable into two classes, first those which are *general* or belong to all kinds of matter, and second those which are *peculiar* or belong only to particular kinds of matter.

Prop. 3.—The *general* properties of matter are indistructibility (*p.* 47;) extension or the property of occupying a portion of space (*p.* 48;) divisibility (*p.* 49;) impenetrability (*p.* 50;) and inertia (*p.* 45.)

Prop. 4.—Every particle of matter, and also all masses, have a mutual *attraction* for one another, or endeavour to get near each other; and this attraction is inversely as the squares of the distances.

There are several kinds of attraction, and they have been denominated, gravitation (*p.* 54;) cohesion (*p.* 54;) electric, magnetic (*p.* 59;) affinity or chemical attraction (*p.* 57;) and capillary attraction (*p.* 56.)

Prop. 5.—Attraction of gravitation, or that force by which all the masses of matter tend towards each other, is exerted at all distances.

Prop. 6.—Attraction of cohesion acts only within certain limits, and where its sphere of attraction ends, a *repulsive* force begins.

Prop. 7.—Repulsion except when dependen on electricity or magnetism, is owing to the presence of heat, which latter pervades all matter.

Prop. 8.—The particles of matter are more or less close, according to the quantity of heat among them; but they are never in actual contact (*p.* 63. 68,) and hence *porosity* is usually considered as one of the properties of matter.

Prop. 9.—The *peculiar* properties of matter are density (*p.* 69,) hardness (*p.* 69,) elasticity (*p.* 70,) brittleness (*p.* 71,) malleability (*p.* 71,) ductility (*p.* 73,) pliability (*p.* 74,) tenacity, (*p.* 74,) &c.

SECTION II.—THE MOTIONS OR PHENOMENA OF THE UNIVERSE.

ANALYSIS OF THE SECTION.

The bodies or masses composing the universe may be at rest or in motion, and there is an INERTIA, *or what may be figuratively called a stubbornness in their component atoms, which resists all change, and renders force equally necessary to produce motion, to take it away, or to bend it. Uniform straight motion, therefore, is as naturally permanent as rest. Hence also the motion in a body, measured by its velocity, direction, and quantity of matter, is the measure of the degree and direction of the force or forces which produced it, and of the force or momentum which the body can exhibit again when opposed or made to act itself as a cause of some new motion.*

The two great forces of nature, attraction *and* repulsion, *acting upon* inert matter, *produce the* equable, accelerated, retarded, *and* bent *motions which constitute the great phenomena of the universe.—Tides, currents, winds, falling bodies, &c. obey* attraction.—*Explosion, steam, collision, &c. obey* repulsion. *And as in every case of attraction or repulsion, two masses at least must be concerned, there can be no motion or* action *in the universe, without an equal concomitant and opposite motion or* re-action.

"*Motion*"

Is the term applied to the changing of place among bodies.

Were there no motion in the universe it would be dead. It would be without the rising or setting sun, or river-flow, or moving winds, or sound, or light, or animal existence. To understand the nature and laws of the motions or changes which are going on around him, is to man of the greatest importance, as it enables him to adapt his actions to what is coming in futurity, and often to interfere so as to control and direct futurity, for his special purposes.

Motion is described in any particular case, by referring to certain objects and certain standards of velocity.—A man sitting on the deck of a sailing ship has *common* motion with the ship: if walking on the deck, he has *relative* motion to the ship: but if he be walking towards the stern, just as fast as the ship advances, he is at rest relatively to the bottom or shore. A ship sailing against the tide, just as fast as the tide runs, has rest relatively both to the earth and water. *Absolute* motion is that which is relative to the whole universe, or to the space in which the universe exists. We have no means of ascertaining such: for although we know how fast our globe whirls upon its axis and round the sun, we have no measure of the motion of the sun himself—revolving probably round some more distant centre, and carrying all the planets along with him.

Motion is called *rapid*, as that of lightning—*slow*, as that of the sun-dial shadow: both terms having reference to ordinary intermediate velocities. It is called *straight*, or *rectilineal*, in the observed path of a falling body—*bent*, or *curvilinear*, in the track of a bullet shot obliquely—*accelerated*, in a stone falling to the earth—*retarded*, in the stone thrown upwards while rising to the point where it stops before again descending.

"*The inertia of bodies, resisting change of state, whether they be in motion or at rest.*"

That bodies tend to continue in the state of motion or of rest in which they happen to be, so as to render force necessary to change the state, is seen in the following facts. The scientific term used to express the general truth is *inertia*, and sometimes the words *obstinacy* and *stubborness* have been substituted as farther explanatory.

When the sails of a ship are first spread to receive the force or impulse of the wind, the vessel does not acquire her velocity at once, but slowly, as the continuing force gradually overcomes the inertia of her mass. If the sails are afterwards suddenly taken in, she does not lose her motion at once, but slowly again, as the continued resisting force of the water destroys it.

Horses must make a greater effort at first to put a carriage into motion, than to maintain the motion afterwards. And a strong effort is required to stop a moving carriage.

When a carriage hanging from springs first begins to move, the body of it appears to fall back, and a person within, seems to be suddenly thrown against the back cushion. When the carriage stops again, the body swings forward, and if the stoppage be very sudden, a careless passenger, may find his head pressing through a front glass. These particulars prove the inertia, first of rest, and secondly of motion.

A man standing carelessly at the stern of a boat, when the boat begins to move, falls into the water behind; because his feet are pulled forward, while the inertia of his body keeps it where it was, and therefore without its support. The stopping of a boat, again, illustrates the opposite inertia of motion, by the man's falling forward.

A bad rider on horseback may be left behind, when his horse darts off suddenly; or may be thrown off on one side by the horse starting to the other. A horse at speed, stopping suddenly, often sends his cavalier over his ears:—as was mortifyingly experienced by a coxcomb who choose to canter along a footpath, to the annoyance of the company, and whose horse, on hearing the word *halt* loudly addressed to it by a waggish spectator who knew its military history, suddenly stood, and got rid of its load. The will of the beau had sinned grossly against the law of propriety, but his body very perfectly obeyed the laws of inertia and gravity, by shooting forward in its parabolic curve to the earth.

A young and not yet skilful Jehu having run his phaeton against a heavy carriage on the road, foolishly and dishonestly excused his awkwardness, in a way which led to his father's prosecuting the old coachman for furious driving. The youth and his servant both deposed, that the shock of the carriage was so great as to have thrown them over their horses' heads, and thus they lost the cause, by unwittingly proving, that the faulty velocity was their own.

A man jumping from a carriage at speed, is in great danger of falling after his feet reach the ground; for his body has as much forward velocity, as if he had been running with the speed of the carriage; and unless he advance his feet as in running, to support his advancing body, he must as certainly be dashed to the ground, as a runner whose feet are suddenly arrested. A man racing who receives a signal to stop, and a man jumping from a flying vehicle, must check their motion nearly in the same way.

A person wishing to leap over a ditch or chasm, makes a run first, that the motion thereby acquired may help him over. A standing leap falls much short of a running one.

An African traveller saw himself followed by a tiger, from which he could not escape by running; but perceiving that the animal was watching an opportunity to seize him by the usual spring or leap, he artfully led it to where the plain terminated in a precipice hidden by brush-wood, and he had just time to transfer his hat and cloak to a bush, and to retreat a few paces, when the tiger sprung upon the bush, and by the motal inertia of its body, was carried over the precipice, and destroyed.

From a glass of water suddenly pushed forward on a table, the water is spilt or left behind, but if the glass be already in motion, as when carried by a person walking, and if it then be suddenly stopped by coming against an impediment, the water is thrown or spilt forward.

A servant carrying a tray of glasses or china in the dark, and coming suddenly against an obstacle, hears all his freight slipping forward and crashing at his feet: and a too hurried departure with such a load causes equal destruction, on the opposite side.

The actions of beating a coat or carpet with a cane, to expel the dust; of shaking the snow from one's shoes, by kicking against the door-post; of knocking a dusty book against a table, or shutting it violently—all illustrate the same principle.

If a guinea be laid on a card, already resting on the point of the finger, a smart fillip or blow to the edge of the card will cause it to dart off, but the guinea, by its inertia, will remain resting on the finger.

When we desire a person, with suspected disease of the brain, to shake his head, and tell whether and where he feels pain, we are doing nearly as if we touched the naked brain with the finger to find the tender part; for the inertia of the brain, when the skull is moved, causes a momentary pressure between it and the skull, almost equivalent for our purpose to such a touch.

This kind of pressure is sufficient to break and destroy tender wares—as glass or eggs—in packages which are too suddenly moved or stopped.

A weight suspended by a spring on ship-board is seen vibrating up and down as the ship pitches with the waves. It seems to fall as the ship rises, and to rise as the ship falls: but the motion is really in the ship, and the rest is in the weight. A heavy weight so supported, and connected with a pump-rod, would work the pump.

Like the weight last mentioned, the mercury of a common barometer on ship-board is seen rising and falling in the tube; and until the important improvement was lately made, of narrowing the tube in one place to prevent this, the barometer was useless at sea. The explanation is, that the tube rises and falls with the ship, from being connected with it; but the mercury, which plays freely in the tube, and is supported by the atmospheric pressure, tends, by its inertia, to remain at rest, and thus makes the motion of the ship apparent.

Like the mercury in the barometer tube on ship-board, the blood in the vessels of animals is similarly affected under similar circumstances. In a long vein below the heart, when the body falls, the blood, by its inertia and the supporting action of the vessels, does not fall so fast, and therefore really rises in the vein: and as there are valves in the veins preventing return, the circulation is thus quickened without any muscular exhaustion on the part of the individual. This helps to explain the effect of the movement of carriages, vessels at sea, swings, and of passive exercise generally, on the circulation, and leaves it less a mystery why these are often so useful in certain states of weak health.

If a cannon ball were to break to pieces in its flight, its parts would still advance with the previous velocity. Thus also, in the deadly contrivance of the Shrapnel shell, which is a case containing hundreds of musket bullets, these being set loose at the desired distance from the devoted body of men, retain the forward velocity of the shell, and spread death around like the discharge on the spot of a whole battalion of musquetry.

On the awful occasion of a ship in rapid motion being suddenly arrested by a sunken rock, all things on board, men, guns, and furniture, start from their places and dash forwards; and the inertia or motal obstinacy of the stern parts of the ship, by pressing forward, crushes the bow against the rock.

"*Motion as naturally permanent as rest.*"

From the instances now given, it is seen that a body at rest would never move if force were not applied, and that a body put into motion retains motion, at any rate for a time, after the force has ceased; still there is a feeling, from common experience, that motion is an unnatural or forced state of bodies, and that all moving things, if left to themselves, would gradually come to rest. It is recollected that a stone projected comes to rest, or a wheel left moving, or a bowl rolling on the green, or the waves heaving after a storm—and, in a word, that there is no perpetual motion on earth.

On more attentive consideration, however, it may be perceived that there are great differences in the duration of motions, and that the differences are always exactly proportioned to evident causes of retardation, and chiefly to *friction* and the *resistance of the air.*

Friction is the resistance which bodies experience when rubbing or sliding upon each other; and however much it may be diminished by art, it can in no case be annihilated. Air-resistance again, to motions going on in air, is of the same nature as water-resistance, to motions going on in water, only less in degree; and as advancing science has shown the true nature of our atmosphere, the amount of this resistance is perfectly ascertained.

A smooth ball rolled on the grass soon stops—on a green cloth over a smooth plank it goes longer—on the bare plank longer still—on a smooth and level sheet of ice, it hardly suffers any retardation from friction, and, if the air be moving with it, will reach a distant shore.

Two little windmill wheels, set in motion together with equal velocity, but of which one has the flat sides of the vanes turned to their course, and the other the edges, if moving in the air, will stop at very different times, but if tried in a vessel from which the air has been removed, they will stop exactly together.

As it is to facilitate the motion of fishes, in the water, that they are of sharp form before and behind; so is it to facilitate the motion of birds in the air that they have somewhat of similar form.

A large spinning-top, with a fine hard point, set in motion in a vacuum, and on a hard smooth surface, will continue turning for hours.

A pendulum in a vacuum has only to overcome slight friction at its point of suspension, and therefore, if once put in motion, will vibrate for a whole day or more.

But it is in the celestial spaces that we see motions completely freed from the obstacles of air and friction—and there they slacken not.

Had the human eye, unassisted, been able to descry the four beautiful moons of Jupiter, wheeling around him for these thousands of years, with such unabated regularity, and which now form, to the telescope of the astronomer, a perfect and magnificent time-piece in the sky—or had science long proved that the velocity imparted to our globe, when first launched into its present orbit, still wheels it along as swiftly as in the days of the first man, this error or prejudice that motion is always tending to rest, would never have arisen.

Indeed, had this, and other truths of the same class now known, been long familiar to the common mind, the opposite prejudice would as probably have obtained, that motion is the natural state, and rest a forced or unknown state. We know of nothing which is absolutely at rest. The earth is whirling round its axis and round the sun; the sun is moving round his axis and round the centre of gravity of the solar system, and, doubtless, round some more remote centre in the great universe, carrying all his planets and comets about his path.

If there were any natural tendency in moving bodies to stop, a thing floating in a trough of water, on board a sailing ship, should always be found at the end of the trough nearest the stern; and in all the seas and lakes of the earth, the floating things would be accumulated on the western shores, because the surface of the earth is always turning to the east. We know that neither of these suppositions is the truth: and a man on board a moving ship can throw a ball just as far towards the bow as towards the stern; although in the two cases the velocity, as regards the earth, is so different.

The state of the objects around us on the surface of the earth, which surface near the equator we know to be revolving with a velocity of 1,000 feet per second, is well exemplified, on a smaller scale, by that of the furniture in the cabin of a sailing ship. An admiral may sit there, surrounded by his books, telescopes, quadrants, time-pieces, &c.; and seeing them always in the same relative places, he may at last cease to think of his own motion and of theirs; and if he looked not abroad, and the ship went on uniformly, he would really be as insensible of the motion, as men on shore are of the whirling of the earth. It would make no difference in the two cases, whether the ship were sailing one mile or fifteen in the hour, or whether the earth were turning once in twenty-four hours, or, like the planet Jupiter, once in ten.

Thus, we perceive, that whatever *common* motion objects may have, it does not interfere with the effect of a force producing any new relative motion among them. All the motions seen on earth are really only slight differences among the common motions: as in a fleet of sailing ships, the apparent changes of place among them are in truth only slight alterations of speed or direction, in their individual courses. This explains why men are not sensible of the rapid motion of the earth, all things moving at the same rate; and why a man in the hold of a ship cannot say whether the rushing of water, which he hears from without, be a rapid tide passing, or the effect of the ship's advance in the river; and why, in a ship sailing in smooth water, or carried by a rapid tide, a man blindfolded, and turned round a few times on his heel, cannot afterwards say whether his face be towards the bow or the stern.

A man continuing to throw upwards a ball or orange, or several of them at once, and to catch and return them alternately, uses no difference of art as regards them, whether he be standing on the earth and whirling with it, or on a sailing ship's deck, or in a moving carriage, or on a galloping horse's back. He and the oranges have always the same forward common motion. And when a man, standing on a galloping horse, leaps through a hoop held across his course, he does not leap forward—for this would throw him over the horse's ears—but merely jumps up, and allows his motal inertia to carry him through.

The reason that a lofty spire or obelisk stands more securely on the earth than a pillar stands on the bottom of a moving wagon, is, not that the earth is more at rest than the wagon, but that its motion is uniform.—Were the present rotation of our globe to be arrested but for a moment, imperial London, with its thousand spires and turrets, would be swept from its valley towards the eastern ocean, just as loose snow is swept away by a gust of wind.

Ignorance of the law of motal inertia led a story-telling mariner to assert, as a proof of the fast sailing of his favourite ship, that when a man one day fell from the mast-head, the ship had slipped from under him before he reached the deck: the fact being, that he must have fallen on the same part of the deck, whether the ship were in motion or at rest, because his body had just the motion or rest which belonged to her.

Another wise man, reflecting that the earth turns round once in twenty-four hours, proposed rising in a balloon, and waiting aloft until the country which he desired to reach should be passing under him.

"Motion naturally uniform." (*See the analysis.*)

It is only repeating that a body cannot acquire or lose motion without a fresh cause, to say that free motion must be *uniform*.

The perfect uniformity of undisturbed motion, is proved by every fact observed in the universe. If any continued motion, as of a planet for instance, be found at one time to have a certain relative velocity to some other motion, the same relation is found always to hold: or deviations from perfect uniformity are always exactly proportioned to the disturbing causes.

Had motion not been in its nature uniform, man could have formed no rational conjecture or anticipation as to future events; for it is by assuming for instance, that the earth will continue to turn uniformly on its axis, that he speaks of *to-morrow* and of *next week*, &c., and that he makes all his arrangements for future emergencies: and were the coming day, or season, or year, to arrive sooner or later than such anticipation, it would throw such confusion into all his affairs, that the world would soon be desolate.

To calculate futurities, then, or to speak of past events, is merely to take some great uniform motion as a standard with which to compare all others; and then to say of the remote event, that it coincided or will coincide with some described state of the standard motion. The most obvious and best standards are the whirling of the earth about its axis, and its great revolution round the sun. The first is rendered very sensible to man by his alternately seeing and not seeing the sun, and it is called *a day;* the second is marked by the succession of the seasons, and it is called *a year*. The earth turns upon its axis about 365 times while it is performing one circuit round the sun, and thus it divides the year into so many smaller parts; and the day is divided into smaller parts, by the progress of the earth's whirling being so distinctly marked, in the constantly varying direction of the sun, as viewed from any given spot on the face of the earth.—When advancing civilization made it of importance to man to be able to ascertain with precision the very instant of the earth's revolution, connected with any event, various contrivances were introduced for the purpose. Such have been, sun-dials, where the shadow travels progressively round the divided circle; the uniform flux of water through a prepared opening; the flux of sand in the common hour-glass, &c. But the very triumphs of modern ingenuity and art are those astronomical clocks and watches, in which the counted equal vibrations of a pendulum, or balance-wheel, have detected periodical inequalities even in the motion of the earth itself, and have directed attention to unsuspected disturbing causes, important to be known.

"Force is required to bend motion."

If a body moving freely cannot vary its velocity without a cause, neither can it vary its course without a cause; and free motion, therefore, is ***straight*** as well as ***uniform***.

A ball shot directly up or down gives men their simplest idea of straight motion.

A bullet or arrow, projected horizontally, is gradually drawn downwards by the attraction of the earth, but it deviates neither to the right hand nor to the left.

William Tell, trusting to the natural straightness of motion, obeyed the tyrant's order, and shot at an apple placed on his child's head.

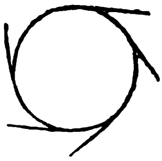
And the right eye of Philip of Macedon is said to have been destroyed by an arrow which brought a label on it, telling its destination.

Riflemen hit the very spot on the target which they choose to aim at.

A stone in a sling, the moment it is set at liberty, darts off as straightly as an arrow, or a bullet from a gun-barrel, and it is only because the point of its circle from which it should depart cannot in practice be accurately determined, that the same sure aim cannot be taken with it.

A body moving in a circle, then, or curve, is constrained to do what is contrary to its inertia.

A person, on first approaching this subject, might suppose that a body which for a time has been made to move in a circle, should naturally continue to do so when set at liberty. But on reflecting that a circle may be considered as made up of an infinite number of little straight lines, and that the body moving in it has its motion bent at every step of the progress, the reason is seen why constant force becomes necessary to keep it there, and just equal to the inertia with which the body tends, at every point of the circle, to pursue the straight line, called a tangent, of which that point, as seen in the figure, is the commencement.



The force required to keep the body in the bent course is called *centripetal*, or centre-seeking force; while the inertia of the body, tending outwards, that is to move in a straight line, is called the *centrifugal* or centre-flying force.

A sling-cord is always tight while the stone is whirling: and its tension is of course the measure, both of the centripetal and centrifugal force.

Bodies laid on a table, which is made to whirl as a horizontal wheel, are quickly thrown off.

In a corn-mill, the grain being admitted between the stones through an opening in the centre of the upper one, is then kept turning round between them, and is always tending and travelling outwards until it escapes as flour from the circumference.

A man, if he lie down on a turning millstone with his head near the edge, falls asleep or dies of apoplexy, from the new pressure of blood on the brain.

A wet mop, or bottle-brush, made to turn quickly on its handle as an axis, throws the water off in all directions and soon dries itself.

Sheep, in wet weather, thus discharge the water from their fleeces by a semi-rotatory shake of the skin. Water dogs, on coming to land, dry themselves by the same action.

A tumbler of water, placed in a sling, may be made to vibrate like a pendulum with gradually increasing oscillation, and at last to describe the whole circle, and continue revolving about the hand, without spilling a drop. The water, by its inertia of straightness, or centrifugal force, tends more away from the centre of motion towards the bottom of the tumbler, even when that is uppermost, than towards the earth by gravity.

In the same manner as solid bodies laid on a whirling table are thrown off, so water in a vessel which is made to spin round in any way, as on the centre of a horizontal wheel, instead of lying at the bottom, is raised up all round, against the sides of the vessel.

Water, poured obliquely into a funnel, runs round the interior of it, and often leaves an open passage of air all the way down through it, as if there were merely a lining of water to the funnel. The centrifugal force of the turning water, is a chief reason of this phenomenon. Another reason will be considered further on, under the head of atmospheric pressure.

Great whirlpools at sea, and smaller ones, or eddies in rivers, occur whenever a current is obliged suddenly to bend, as in rounding a point of land or a rock. The water, by tending to continue its straight motion, falls in behind the obstruction, reluctantly as it were, and leaves there a pit surrounded by a liquid revolving ridge. Charybdis in the Mediterranean, and the great whirlpool off the Norwegian coast, are noted examples.

It is owing to the centrifugal force in any bending part of a stream of water, that when a bend has once commenced, it increases, and is soon followed by others, until that complete serpentine winding is produced, which characterizes most rivers in their course across extended plains. The water being thrown by any cause to the left side, for instance, wears that into a curve or elbow, and acts constantly by its centrifugal force on the outside of the bend, until rock or higher land resist the gradual progress ; from this limit being thrown back again, it wears a similar bend to the right, and after that another to the left, and so on.

Carriages are often overturned in quickly rounding corners. The inertia carries the body of the vehicle in the former direction, while the wheels are suddenly pulled round by the horses into a new one. A loaded stage coach running south, and turned suddenly to the east or west, strews its passengers on the south side of the road. Where a sharp turning in a carriage-road is unavoidable, the outside of the bend should always be made higher than the inside, to prevent such accidents.

A man or a horse turning a corner at speed, leans much inwards or towards the corner, to counteract the centrifugal force, that would throw him away from it.

In skaiting with great velocity, this leaning inwards at the turnings becomes very remarkable, and gives occasion to the fine variety of attitudes displayed by the expert; and if a skaiter, in running, finds his body incline to one side, and in danger of falling, he merely makes his skait describe a slight curve towards that side, and the inertia of straightness, or centrifugal force of the body, refusing as it were to follow in the curve, restores the perpendicularity. Skaiting becomes to the intelligent man an intellectual, as well as a sensitive or bodily treat, from its exemplifying so pleasingly the laws of motion.

The last example explains, also, why a hoop rolled along the ground goes so long without falling: if it incline to one side, threatening to fall, by that very circumstance its course is bent to that side, and as in the case of the skaiter who turns his foot, the supporting base is again brought directly under the mass of the body.

A coin dropt on the table or floor often exhibits the same phenomenon. It is said to run and hide itself in the corner. Just before falling, if not obstructed, during several revolutions, its base or touching part describes an increasing spiral, the minute examination of which is a pleasing mathematical exercise.

The reason also why a spinning top stands, will be understood here. While the top is perfectly upright, its point, being directly under its centre, supports it steadily, and although turning so rapidly, has no tendency to move from the place; but if the top incline at all, the side of the peg, instead of the very point, comes in contact with the floor, and the peg then becomes a little wheel or roller, advancing quickly, and, with its touching edge, describing a curve somewhat as a skaiter does, until it come directly under the body of the top as before. It thus appears that the very fact of the top inclining, causes the point to shift its place, and so that it cannot rest until it come again directly under the centre of the top. It is remarkable that even in philosophical treatises of authority the standing of a top is still vaguely attributed to *centrifugal force.* Hence some persons believe, that a top spinning in a weighing scale, would be found lighter than when at rest; and many most erroneously hold that the centrifugal force of the whirling, which of course acts directly away from the axis, and quite equally in all directions, yet when the top inclines, becomes greater upwards than downwards, so as to counteract the gravity of the top. The way in which centrifugal force really helps to maintain the spinning of a top is, that when the body inclines or begins to fall in one direction, the motion in that direction continues until the point describing its curve has forced itself under the body again.

By reason of contrifugal force also, it is easier to do feats of horsemanship in a small ring, as at our theatres, than if the animal were running on a straight road. We see the man and horse always inclining inwards, to counteract centrifugal force, and if the rider tend to fall inwards, he has merely to quicken the pace, if to fall outwards, he has to slacken it, and all is righta gain.

If a pair of common fire-tongs, suspended by a cord from the top, be made to turn by the twisting or untwisting of the cord, the legs will separate from each other with force proportioned to the speed of rotation, and will again collapse when the turning ceases. Mr. Watt adapted this fact most ingeniously to the regulation of the speed of his steam-engine. His *steam-governor* may in truth be described as a pair of tongs with heavy balls at the ends, to make their opening more energetic, attached to some turning part of the machine. If the engine move with more than the assigned speed, the balls open or fly asunder, and by a simple contrivance are made to move a valve which contracts the steam tube; on the contrary, with too slow a motion, they collapse and open the valve.

A half-formed vessel of soft clay, placed in the centre of the potter's table,—which is made to whirl, and is called his wheel,—opens out or widens merely by the centrifugal force of its sides, and thus assists the worker in giving its form.

A ball of soft clay, made to turn quickly by a spindle fixed through its centre, soon ceases to be a perfect ball. It bulges out in the middle, where the centrifugal force is great, and becomes flattened towards the ends, where the spindle issues.

This is exactly what has happened to the ball of our earth. It has bulged out seventeen miles at the equator, in consequence of its daily rotation, and is flattened at the poles in a correponding degree.

In the planets Jupiter and Saturn, of which the rotation is much quicker than of our earth, the middle or equator bulges out still more—even so as to offend an eye which expects a perfect sphere.

A mass of lead that weighs one thousand pounds at our pole, weighs about five pounds less at the equator, by reason of the centrifugal force.

If the rotation of our earth were seventeen times faster than it is, the bodies or matter at the equator would have centrifugal force equal to their gravity, and a little more velocity would cause them to fly off altogether, or to rise and form a ring round the earth like that which surrounds Saturn. Saturn's double ring seems to have been formed in this way, and is now supported chiefly by the centrifugal force of the parts. Were it to crumble to pieces, the pieces might still revolve, as so many little satellites. His true satellites are only more distant masses sustained in the same manner. Our earth and the other primary planets have the same relation to the sun that these satellites have to Saturn, all being sustained by a beautiful balance between centrifugal force and gravity.

"The quantity of motion in a body measured by the velocity and quantity of matter."*

If a single atom of matter were moving at the rate of one foot per second, it would have a definite quantity of motion expressed by these words; and if it were moving ten feet per second it would have ten times the quantity. Again, in a mass consisting of many atoms, the quantity of motion would be still as much greater, as there were more atoms in it than one.

By experiment it is found, that if a ball of soft clay of one pound, suspended by a cord as a pendulum, be allowed to fall, with a velocity of ten feet per second, against a quiescent ball of nine pounds suspended in the same way, the two, after contact, will move on together at the rate of one foot per second, the original quantity of motion being then diffused through ten times the quantity of matter, and therefore exhibiting only one-tenth of the velocity.

---

* The quantity of motion in a body is called its momentum.

A cannon ball of a thousand ounces, moving one foot per second, has thus the same quantity of motion in it as a musket ball of one ounce, leaving the gun-barrel with a velocity of a thousand feet in the second.

" *The quantity of motion in a body is the measure of the force which produced it;*"

The experiment of the balls of clay mentioned above furnishes one instance of this truth. Again, a body falling for ten seconds, acquires ten times as much velocity as by falling for one second, its motion thus measuring the force of gravity which has been exerted upon it.

When a large body or mass of many atoms falls, it of course has as much more motion than a smaller body, as there are more atoms in it than in the smaller: but as gravity acts equally on every atom, the force causing either body to fall is still exactly indicated by the quantity of motion in it.

A large body or a mass of many atoms naturally falls with the same velocity as a smaller body or a single atom; for gravity pulls equally at each atom, and must overcome its inertia equally, whether it be alone or with others.

This remark contradicts the popular opinion, that a large and heavy body should fall to the earth much faster than a small and light one; an opinion which has arisen from constantly seeing such contrasts, as the rapid fall of a gold coin, and the slow descent of a feather. The true cause of the contrast is, that the atoms of the feather are much spread out, so as to be more resisted by the air than those of the gold. If the two be let fall together in a vessel from which the air has been extracted, as in the common air-pump experiment, they arrive at the bottom in exactly the same time: and even in the air, if the coin be hammered out into gold leaf, it will fall still more slowly than the feather. One brick dropped from a height, reaches the earth as soon as ten bricks let fall near it, whether they be connected or separate—as a single horse may reach the goal as soon as ten horses galloping abreast.

When a large and a small ship are seen sailing with the same velocity, the surface of canvass or sail which they spread to catch the force of the wind, is proportioned to the difference of resistance which the water offers to the two.

A man's force will move a small skiff quickly, a loaded barge very slowly, and a large ship in a degree scarcely to be perceived. In each case, however, the quantity of motion may be the same, and a true measure of the force which produced it.

A musket and a cannon ball, moving with the same velocity, indicate, by the different quantities of motion in them, the difference of the forces which caused their motion—the force of an ounce of gunpowder perhaps in the one case, and of pounds in the other.

A ball of one pound weight, impelled by a given force, moves twice as fast as a ball of two pounds impelled by the same; yet, although the velocities are different, the quantities of motion, as ascertained by the rule already given, are equal, and indicate an equality of producing force,

" and of the force or momentum which it can exhibit again."
(See the analysis, page 46.))5

Bodies may be regarded as reservoirs of force or motion, always ready to return as much as they have received. ***Momentum*** is the name given to the motion in a body, with reference to the production by it of new motions or the overcoming of resistances, and is but another term for the ***quantity of motion.***

A cannon ball, according to the quantity of motion in it, may have only the force or momentum that will bruise a plank, or it may have enough to penetrate a tree, or even to shoot its rapid way through a block of the hardest stone.

A small block of wood, floating against a man's leg with moderate velocity, would hardly be felt; but a loaded barge, coming at the same rate, and pressing it against the quay, might break the bones; a large ship, approaching with this speed, would crush his body against any fixed obstacle; and an island of ice, opposed in its approach to another, even by a first-rate man of war, would destroy this as meeting barges destroy a floating egg-shell.

A hail-stone falling, strikes rudely; a stone rolled from a height, as of old, by the besieged against besiegers, may carry death with it to many; an avalanche, breaking from its hold on a mountain steep, may sweep away a village.

To meeting bodies the shock is the same, whether the motion be shared between them or be all in one.

If a running man come against a man who is standing, both receive a certain shock. If both be running at the same rate in opposite directions, the shock is doubled. In some such cases, as where swift skaiters have met, the shock has proved fatal.

A man's skull is fractured as certainly by its being dashed against a tree while he is on a galloping horse, as by the blow of a lance or beam shot at him with the velocity of the horse.

The meeting fists of boxers not unfrequently dislocate or break bones.

When two ships in opposite courses meet at sea, although each may be sailing at a moderate rate, the destruction is often as complete to both, as if with a double velocity they had struck on a rock. Many melancholy instances of this kind are on record. In the darkness of night a large ship has met one smaller and weaker, and, in the lapse of a few seconds, have followed the shock of the encounter, the scream of the surprised victims, and the horrible silence when the waves again closed over them and their vessel for ever.—In November, 1825, on the coast of Scotland, the Comet steam-boat was thus destroyed, and carried to the bottom with her about seventy passengers, into whose ears the rushing water entered before the sounds of arrested music and joy had died away.

"*Direction of the force or forces producing motion.*"

When only one force acts on a body, the body obeys in the exact direction of the force.

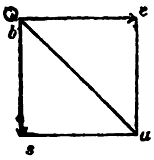
A ball floating in water, or lying on smooth ice, is driven exactly south by a wind blowing to the south. A bullet issues from the mouth of a cannon, in the direction of the axis of the cannon—which is, as the force impels it.

When two or more forces act upon a body at the same time, as it cannot move two ways at once, it holds a middle course between the directions of the separate forces. This course is called the ***resulting direction,*** viz. resulting from the *composition of the forces.*

A ball or ship moving south by a direct wind, may, at the same time, be carried east, just as fast, by a tide or current moving east: every instant, therefore, it will go a little ***south*** and a little ***east,*** and really will describe a middle line pointing ***south-east.***

These particulars may be well represented on paper, as by fig. 1: where

Fig. 1.



b is the original place of the ball or ship, *e* the east, *s* the south, and *b a* the middle line pointing to the south-east, and showing the true course of the vessel. This figure is called the *parallelogram of forces,* and is an important help to the understanding of many facts in natural philosophy. The minute investigation of the subject belongs to the *science of measures,* or technical mathematics; but the general truths are quite intelligible to common sense, and the mathematics of common experience.

When two forces act upon a body, like the wind and tide in the last example, the result is the same, whether they act together or one after the other. For instance, if the wind drive a vessel one mile south, as from *b* to *s*, fig. 1, and immediately afterwards the tide drive it one mile east, as from *s* to *a*, the vessel will be in the same place at last, viz. at, *a*, as if she had been driven at once south-east, in the line *b*, *a*, by the simultaneous action of the two. Therefore by drawing the lines *b s* and *b e* to represent the force and direction of the two causes of motion, and by then adding one of them, or an equivalent, to the end of the other, as *s a* to *b s*, or *e a* to *b e*, the square or parallelogram is sketched, of which the middle line, or *diagonal*, as it is called, shows the resulting direction of the forces, and the true course of the body obeying them.

What is thus true of the effect of continued forces like wind and tide, is true also of momentary impulses, like the blows of clubs simultaneously striking a ball, or of two billiard balls striking a third.*

When the forces exactly cross each other, and are equal, as in the case of the ship above supposed, the figure becomes a square, as at fig. 1; but if one of the forces be greater than the other the figure becomes oblong, as at fig. 2; if the forces cross obliquely, the figure becomes as at fig. 3;

Fig. 2.

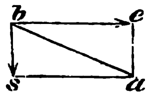


Fig. 3.

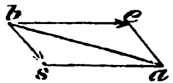
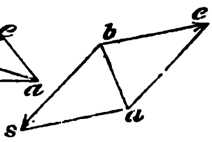
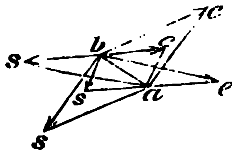


Fig. 4.

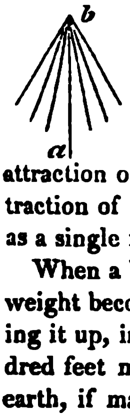


and if they cross in an opposing direction, it will be as at fig. 4. In all the cases, however, the diagonal still shows the *result*. It is evident that the same line may be the diagonal of many figures, as seen at fig. 5; and therefore, that very different degrees and directions of combined forces may produce the same *result*.

Fig. 5.



In all cases where the two forces are equal, with whatever obliquity they cross each other, the resulting direction must be mid-way between them.—Thus a boat impelled by oars, goes straight, although the action of the oars is rarely direct; because the changing obliquity of the force is always the same on both sides.—This explains also why a bird flying, or a man swimming, holds a perfectly straight course, although in both cases the direction of the impelling forces is constantly varying.—And it explains why a body suspended, as a plummet, or falling to the earth, as an apple does from a tree, is always in a line towards the centre of the earth: for, while the part of the earth immediately under the body is pulling it straight down to the centre, the action of parts on any one side of the perpendicular is exactly counterbalanced by the action of corresponding parts on the opposite side; and the perpendicular is still the diagonal or middle line of every pair of attracting parts. In this figure *a b* represents the common diagonal. In speaking of the attraction of our earth, therefore, which really is the united attraction of all the individual atoms, we may always consider it as a single force acting towards the centre of the earth.



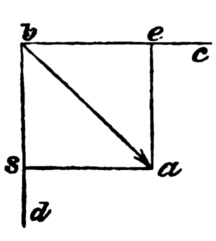
When a body is carried below the surface of the earth its weight becomes less, because the matter then above it is drawing it up, instead of down, as before. A descent of a few hundred feet makes a sensible difference, and at the centre of the earth, if man could reach it, he would find things to have no weight at all; and there would be neither up nor down, because bodies would be attracted equally in all directions.

Forces crossing each other so obliquely as to be represented by lines drawn in almost opposite directions, would form a parallelogram having scarcely any breadth, that is to say, the diagonal would approach to nothing; showing thus, that opposing forces neutralize or destroy each other. In fig. 4, by reason of this crossing, the *resultant* is less than either of the constituents.

For the same reason, when forces cross so acutely as to advance nearly parallel to each other, the *resultant* is longer than either. (Fig. 3.)

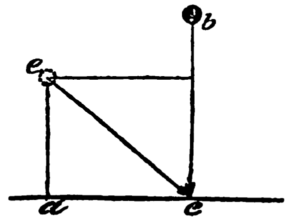
When more than two forces act on a body, the resulting direction may be found, first of two, and then of the last *resultant*, with each of the others successively :—or the forces may be represented on paper by lines tacked together, of which one denotes the strength and direction of each ; the extremity of the last line will mark the place of the body after being acted upon by the combined forces. A sailor, to know the true place of his ship and the course which she has steered, considers, first, the forward progress as found by the log, then the leeway or sideward motion produced by a cross wind, and then the effect of any tide or current in which he may be sailing.

Resolution of Forces is a phrase pointing to another important use of such parallelograms or figures as have just been described, *viz.* the enabling us, when any force or motion is given, to find the forces in any other directions of which it may be the *resultant*, and the forces into which it may be again resolved.



If a line be given representing a single force, or result of forces, as *b a*, and if it be desired to know how much force there is in this resultant capable of acting in another direction, as *b c*, and in another as *b d* ; it is only necessary to draw lines in these directions, from the commencement of *b a*, and to cut such lines by others drawn directly upon them—or at right angles to them, as it is termed—from the other end : the lengths of *b c*, and *b d*, so cut off, *viz.* *b e*, and *b s*, show the proportions required.

It is thus that a sailor, who knows how far he has sailed in a particular direction, finds out how much he has gone north and east, or south and west; in other words, finds out the difference of latitude and longitude between his present place and a former one.



Thus again, if a ball *b* strike a table, *a c*, with velocity, direction, and force, each of which is represented by the line *b c*; and if the ball be supposed afterwards with the same velocity to approach the table in the oblique direction *e c*, it will then strike with as much less force than before, as the line *e a* is shorter than *e c*. For *e a* is found, according to the rule for decomposing a force, given above; and, to common sense, it is obvious, that if the whole velocity of the ball be represented by *e c* the directly downward or falling velocity towards the table is marked by the line *e a*.

This last figure explains the important cases of the force of wind on ships' sails, and on windmill vanes; and the force of water on float-boards, and on water-wheels, &c.; showing that the force of the moving body on the flat surface is not proportioned to the speed with which the body may be passing along near the surface, but to the rate of perpendicular approximation.

"*The two great forces of Nature are* ATTRACTION *and* REPULSION." (*Read the analysis.*)

A person, on first approaching this subject, is far from supposing that the beautiful and endless variety of phenomena exhibited in the universe around, are all referable to the two principles, attraction and repulsion, examined in the first section: but such is the truth.—It will first be shown here, how the great classes of accelerated, retarded, and bent motions arise from them.

Attraction.—Until Newton said that what we call *weight* of bodies is merely an instance of that universal attraction of matter which diminishes with increasing distance, it was never suspected that weight was less, high up in the air than on the ground; or on a lofty mountain than on the sea-shore. But this we now know to be the case. However, in studying what goes on in obedience to gravity near the surface of the earth, except in a few very nice cases, gravity may be considered as a uniform power. Man has neither approached the centre of the earth in mines, nor receded from it in balloons, by more than about a thousandth part of his distance from it; and as weight has a certain relation to the distance from the centre, a delicate test was required to discover any difference.

"*Accelerated motion, from gravity.*"

Owing to the inertia of matter, any force continuing to act on a mass which is free to obey it, produces in the mass a quickening or accelerated motion: for as the motion given in the first instant, continues afterwards without any farther force, merely on account of the inertia, it follows that as much more motion is added during the second instant, and as much again during the third, and so on. A falling body, therefore, under the influence of attraction, is as it were a reservoir, receiving every instant fresh velocity and momentum.

It is said that Newton's sublime genius read the nature of attraction in the simple incident of an apple falling before him from a lofty branch in his garden.

The eye which perceives an apple beginning to fall, can follow it for a time and mark the gradual acceleration of its descent, but soon sees its path only as a shadowy line.

A boy letting a ball drop from his hand, can catch it again in the first instant, but after a little delay his hand pursues it in vain.

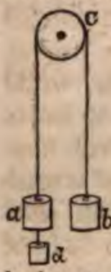
A fragment of rock, detached from the brow of a hill by the lightning stroke, begins its motion slowly; but once fairly launched, it gathers fresh speed and momentum with every instant, and bounds from steep to steep sweeping every obstacle before it.

Any liquid falling from a reservoir, forms a decending mass or stream of which the bulk diminishes from above downwards, in the same proportion in which the velocity increases. This truth is well exemplified by the pouring out of molasses or thick syrup: if the height of the fall be considerable, the bulky mass, which first escapes, is reduced, before it reaches the bottom, to a small thread; but the thread is moving with proportionate speed, for it fills the receiving vessel with singular rapidity. The same truth is exhibited on a mighty scale in the Falls of Niagara; where the broad river is seen, first bending over the precipice a vast slow moving mass, then becoming a thinner and a thinner sheet, until it flashes into the deep below, almost with the velocity of lightning.

When velocity becomes considerable in any case of falling, it cannot be measured accurately by the eye, but its effects ascertain it. A man leaps from a chair with impunity, from a table with a shock, from a high window with fracture of his bones, and in falling from a balloon his body is literally dashed to pieces.

The force of gravity or general attraction is such at the surface of this earth, that in one second of time, it gives to a body allowed to fall, a velocity which, remaining uniform, would carry it, without farther action of gravity, through 32 feet in the next second. As this velocity is gradually acquired, however, the body has only half of it at the half-second, and as much less than half before that time, as it has more than half afterwards; so that it really falls through only half of the 32, *viz.* 16 feet in the first second. In the next second, it falls of course through the whole 32 feet, with 16 additional, from the new action of gravity, in all, three times as much as in the first second; and in two seconds, therefore, it falls altogether four times as far as in one second. At the end of two seconds the velocity is doubled, or is 64 feet per second, so that in the third second the body falls 64, and other new 16, in all, five times as much as in the first second: and in three seconds, therefore, it has descended nine times as far as in one second, &c. Knowing this progress, the velocity acquired by a falling body, and the distance through which it falls, in any given time, are easily accertained; and the height of a precipice, or the depth of a well, may be judged of with considerable accuracy, by marking the time required for a body to fall through the space.

The doctrines of falling bodies are of such importance in the minute examination of many of the phenomena of nature, that much attention has been bestowed upon them. Mr. Atwood's ingenious contrivance by which the motion of falling bodies may be retarded in any desired degree, without the character of the motion being otherwise altered, has enabled experimenters to render evident to the senses all that abstract calculation had anticipated. A pound weight, left quite free, falls towards the ground, sixteen feet in the first second, proving that *attraction* of one pound is just sufficient to overcome the *inertia* of one pound at that rate. But if the inertia were doubled, or tripled, or increased in any other degree, the fall of course would be just so much slower. Now Mr. Atwood's machine in effect increases it, by causing falling weights to overcome not only their own inertia, but also that of other weights.



Thus, *a* and *b*, being weights of two pounds each, balancing each other over the pulley *c*, are moved by a weight of one pound, *d*, hooked to one of them ; and gravity in pulling this down, with force of one pound, has to overcome, not the inertia of one pound, but of five, for the other two weights must move as fast as the one pound does ; and thus, the velocity being reduced to one-fifth of what is natural to a falling body, the descent can be minutely observed. The experiments with Atwood's machine may be varied exceedingly, and they are most interesting.

"Retarded Motion," from gravity.

What has been said of the changing velocity of a falling body, from gravity, is exactly true, in a reversed way, of a rising body exposed to its influence.

A bullet shot directly upwards, every instant loses a part of its velocity, until at last it comes to rest in the sky,—where a soaring eagle might see the messenger of death motionless and harmless for a moment by his side :—the ball then descends again, and so that, at corresponding points of the ascent and descent, but for the resistance of the air, the velocities would be equal; and, on reaching the ground, the body would have acquired exactly the velocity with which it first departed.

It is shown in a preceding paragraph, that a body falls four times as far in two seconds as in one, although the velocity at the end of two seconds is only doubled. For the same reason, a body shot upwards with double velocity, rises four times as far as if shot with a single velocity; if with triple velocity, it rises nine times as far, and so forth.

In aiming for amusement at bodies thrown up into the air, it is easy to hit them near their point of turning, and more difficult always as they are nearer to the ground, whether rising or falling.

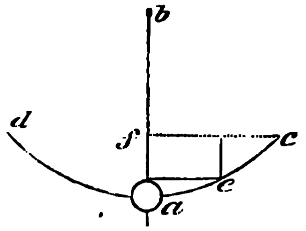
An upward jet of water is small below, where it issues from the pipe with great velocity, but it becomes more bulky as the water loses velocity in ascending, and at the top, it often spreads a little like a palm tree, and any light round solid will continue supported and playing upon its summit.

The rise of a pendulum from the bottom of its arc, is an exact copy, reversed, of its previous descent to that point.

The Pendulum

exemplifies well both accelerated and retarded motion. The name is applicable to any body so suspended that it may swing freely backwards and forwards. When such a body is made of certain form and length, although so simple, it is one of the most admirable contrivances of man's ingenuity.

Galileo having observed the hanging chandeliers of lofty ceilings to continue vibrating long and with singular uniformity, after any accidental cause of disturbance, was led to investigate the laws of the phenomenon; and out of what, in some shape or other, had been before men's eyes from the beginning of the world, his powerful genius extracted the most important results. Independently of the light which the theory of the pendulum has thrown on various branches of physics, the instrument itself, with a few wheels attached, to record its vibrations, has now become the perfect time-keeper, regulating the actions and affairs of men.

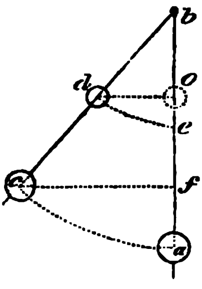


A common pendulum consists of a ball, as *a*, suspended by a rod from a fixed point, as *b*, and made to swing backwards and forwards, or to vibrate, under this point. Being raised to *c*, and then set at liberty, it falls back to *a* with an accelerating motion like a ball rolling down a slope, and when arrived there, it has just acquired momentum enough to carry it to *d*, at an equal elevation on the other side; from this it falls back again, again to rise, and would so go on for ever, but for the impediments of air and friction.—The pendulum is strictly an object of mathematical study, but we shall attempt to give a general idea of its important characteristics in common language.

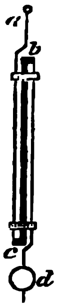
1. The *times of the vibrations* of a pendulum are very nearly equal, whether it be moving much or little, that is to say, whether the arc described by it be large or small. This remarkable property is what makes it a time-keeper. The reason that a large vibration is performed in the same time as a small one, in other words, that the pendulum always moves faster in proportion as its journey is longer—is, that in proportion as the arc described is more extended, the steeper are its beginning and ending, and the more rapidly, therefore, the pendulum falls down at first, sweeps along the intermediate space, and stops at last. It its evident, for instance, that the portion *c e* of the arc is much more steep then the equal portion *e a.*—A pendulum made to vibrate in the curve called a *cycloid*, which towards the extremities of a large arc differs a little from the circle, but very nearly coincides in the central part, has its beats perfectly *isochronous*, or in equal times, under all circumstances.

A common clock is merely a pendulum, with wheel-work attached to it, to record the number of the vibrations, and with a weight or spring having force enough to counteract the retarding effects of friction and the resistance of the air. The wheels show how many swings or beats of the pendulum have taken place, because at every beat, a tooth of the last wheel is allowed to pass. Now if this wheel has sixty teeth, as is common, it will just turn round once for sixty beats of the pendulum, or seconds, and a hand fixed on its axis projecting through the dial-plate, will be the second hand of the clock. The other wheels are so connected with this first, and the numbers of teeth on them so proportioned, that one turns sixty times slower than the first, to fit its axis to carry a minute hand, and another by moving twelve times slower still, is fitted to carry an hour hand.

2. The *length of a pendulum* influences the time of its vibration.



Long pendulums vibrate more slowly than short ones, because, in corresponding arcs or paths, the long pendulum has a greater journey to perform, without having a steeper line of descent. If a pendulum *b a* be twice as long as another *b e*, it has twice as much to fall in its descending arc *c a*, as the other in its arc *d e*, while in corresponding parts of the two paths, the slope or inclination is always equal:—the ball of the long pendulum may be considered as having rolled twice as far down a given slope as the ball of the short pendulum. Now as a body falls four times as far, either directly or on any uniform slope, in two seconds as in one (see page 104,) a pendulum must be four times as long, to beat once in two seconds, as to beat every second. A pendulum of a little more than thirty-nine inches, beats seconds; one of four times that length is required to beat double seconds, and one of one-fourth the length to beat half seconds. As the smallest change in the length of a pendulum alters the rate of going of the clock, a pendulum which beats seconds constitutes an easily found and correct standard of measure. To counteract the dilatation or contraction of pendulums from the changing heat of the seasons, various ingenious contrivances have arisen. One of the best of these is the *gridiron pendulum*, as it is called, from consisting of various rods of metal. It renders the different dilatability by heat of two metals composing it, the cause of unchanged length in the whole. The adjoining sketch may show that if the central rod of brass (here represented by a *strong* line from *b to c*) dilate just as much as the two rods of steel on either side of it (the expansion of brass by heat being about double that of steel,) it will exactly counteract the lengthening of these, and will keep the ball *d* always at the same distance from the point of suspension *a*.

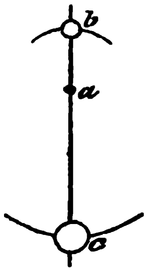


Common clocks are regulated by a screw which lifts or lets down the ball of the pendulum, and so changes the effective length, which is the distance between the point of suspension and what is called the *centre of oscillation*, treated of in the next chapter.

3. The *force of gravity*, of course, is what determines how long the pendulum shall be in falling to the bottom of its arc, and how long in rising, for the ball of the pendulum, as already stated, may be considered as a body descending by its weight on a slope; a change in the force of gravity, therefore, would at once alter the rate of all the clocks on earth. Accordingly, at the equator of our earth, where the gravity of bodies is counteracted in a small degree by the centrifugal force arising from the earth's motion (as explained at *page* 93,) a pendulum vibrates more slowly than elsewhere, and must be made shorter to answer its purpose.

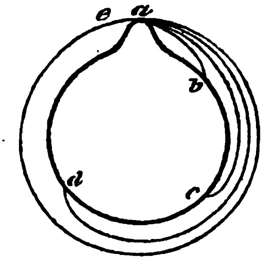
Some astronomical clocks in the present day are so perfect, that they do not err one beat of the pendulum in a year.

There is a small pendulum called a *metronome*, used by musicians for marking time ; which, although very short, may still be made to beat whole seconds, or even longer intervals. The reason of its slow motion is, that its rod is prolonged beyond its axis of support, at *a*, upwards, to *b*, and has a ball upon the top, at *b*, as well as on the bottom, at *c*; which upper ball prevents the under one from moving so fast as it otherwise would, just as a small weight attached to one end of a weighing beam, prevents a greater weight attached to the other end from falling so fast as it would if there were no counterpoise. The rate of motion changes with every change in the distance of the ball *b* from the centre of motion *a*; and the ball *b* is made to slide.



A pocket-watch differs from a clock, in having a vibrating wheel instead of a vibrating pendulum; and as, in a clock, gravity is always pulling the pendulum down to the bottom of its arc, which is its natural place of rest, but does not fix it there, because the momentum acquired during its fall from one side, carries it up to an equal height on the other—so in a watch, a spring generally spiral, surrounding the axis of the balance-wheel, is always pulling this towards a middle position of rest, but does not fix it there, because the momentum acquired during its approach to the middle position, from either side, carries it just as far past on the other side, and the spring has to begin its work again. The balance-wheel at each vibration allows one tooth of the adjoining wheel to pass, as the pendulum does in a clock, and the record of the beats is perserved by the wheels which follow, as already explained for the clock. A main-spring is used to keep up the motion of a watch, instead of the weight used in a clock; and as a spring acts equally well, whatever be its position, a watch keeps time although carried in the pocket, or in a moving ship.

As the rate of a clock is influenced by the length of its pendulum, so is the rate of a watch by the size or diameter of its balance-wheel; and heat which retards the motion of a common clock, by lengthening the pendulum, retards the motion of a common watch by dilating the balance-wheel. Man's ingenuity



A cannon ball shot horizontally from the top of a lofty mountain, would go three or four miles. (The mountain is here represented on an enlarged scale, as standing on the globe, at *a*.) If there were no atmosphere to resist its motion, or if the mountain top were above the surface of the atmosphere, the same original velocity would carry it thirty or forty miles before it fell, as to *b*; with more force still, it would reach to *c*, and with still more to *d*. And if it could be despatched with about ten times the velocity of a cannon shot, it would not have approached nearer to the earth than at first, even when it had again reached round to *e* or to *a*; and its velocity being undiminished, it would perform a second similar tour, and then a third, and so forth: it would, in fact, have become a little satellite, or planetary body, revolving round the earth. In the successive ranges represented in the figure, it is seen that the centrifugal force of the ball, or its tendency to move in a straight line, becomes more and more nearly a counterbalance to gravity, and at last is exactly equal to it. If the force given to the ball were more than sufficient to bring it round again to the level of *a*, it would fly off, or increase its distance from the earth, acquiring somewhat of the eccentric motion of a comet. There may really be such revolving masses above our atmosphere, although invisible to us owing to their smallness. It has been supposed by some, but untenably, that the metoric stones, which fall to the earth every now and then, come from such bodies, or are the entire masses which in some way have become entangled in our atmosphere, and so have lost their forward velocity. The four little planets discovered lately between Mars and Jupiter, are not larger than a six-thousandth part of our earth.

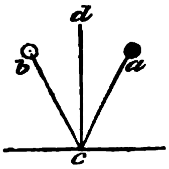
Repulsion—produces *accelerated*, *retarded*, and *bent* motions like attraction, but it acts only at minute distances; while *attraction* draws from the sun, or from the very limits of the universe: *repulsion* acts, for instance, between the adjoining atoms of an elastic fluid. Yet repulsion plays a part in the economy of nature, not at all inferior to its sister attraction. We have already seen, when considering the constitution of masses in *section first*, that repulsion keeps the atoms of all bodies from reaching a complete contact; that with increase of temperature, it causes these atoms to separate, and of a solid to form a liquid, or even an air; that it operates around all masses as if it were a film or covering, preventing their mutual cohesion, &c. &c.

Accelerated motion from repulsion, is seen when the atoms of gunpowder explode and propel the bullet from the bottom of a piece to the muzzle with such rapid increasing velocity. The strength of this repulsion of gunpowder is so much stronger than the strength of gravity or common attraction, that its action on a bullet, during the passage along a barrel of five or six feet in length, may not be overcome by gravity, during an ascent of a mile or more.

A visibly *retarded* motion from repulsion, is exemplified by a moving body coming against a spring, or a bladder full of air, or against the piston handle of an air syringe, so as to compress the air beneath it.

Any elastic body striking against another body and recoiling exhibits in conjunction the phenomena of retardation, acceleration, and often also of bending, from repulsion ; for instance :

An ivory ball driven forcibly against a marble slab, does not stop in the instant that apparent contact takes place, but still advances and compresses that part of the substance which is against the marble,—as is proved by the facts mentioned at page 71. While this compression of the ivory is going on, the resistance made by the increasing repulsion of the particles gradually retards, and ultimately destroys the forward motion of the ball ; and at the instant of its final arrest, the parts in contact, both of the ball and of the marble, being in their greatest degree of compression, act on the ball, and repel it again with gradually accelerating motion, until it leaves the marble, with the same velocity which it had on approaching. The retardation and acceleration take place here within so small a space, and in so short a time, that they are not apparent to sense, but the mind perceives the nature of the phenomenon as distinctly as if the ball rolled against the end of a long steel spring.—If the ball strike the marble obliquely, as from *a* to *c*, it does not rebound in the same line by which it approached, but just as obliquely towards the other side, *viz*, from *c* to *b*; and it then exhibits a bent motion:—*d c* is a perpendicular line showing that the angles formed with it by the lines of the approach and departure of the ball are equal. The important law in physics, of which this case is an example, is usually expressed—"The angles of incidence and of reflection are equal." It applies to all reflected bodies, as balls, waves, sound, light, &c.



If the ivory ball and marble, in the above case, were supposed to be both perfectly hard, and without elasticity, still the repulsion which surrounds all bodies, as a thin covering, preventing their cohesion (see page 63) would act exactly as the real elasticity of the ivory, and would cause a retarded motion until perfect rest came, and then an accelerated motion back again, until the ball recovered its primitive velocity.

Collision between hard bodies always exhibits more or less of the truth now described; when it occurs between soft bodies, as lumps of lead or of moist clay, the approaching parts mutually displace each other, and there is no recoil.

When a straight steel plate, of which the end is fixed in a block, is bent, as by a ball rolling against it, the particles on the side which becomes concave are made to approximate, and there is a resistance or repulsion gradually increasing among them: the particles on the convex side, again, are drawn a little more from each other than natural, and are therefore attracting to return; the recoil of the spring, thus, is owing to both forces trying to replace the particles in their former relative situations.

" *Tides, Winds, &c. are Attraction.*" (Read the analysis p. 78.)

Until we reflect attentively on this subject, we are far from perceiving that all the phenomena of nature are only instances of *attraction* and *repulsion*, acting under variety of circumstances.

Attraction—Tides are raised by the attraction of the moon and sun, and fall again by the general attraction of the earth:—producing in many of the shallower parts of the ocean very rapid currents. They do a great deal of work for man. They carry his ships along the coasts, and up and down the rivers; they turn water-wheels for him; they fill his docks and canals at convenient times; they rise to receive his ships, launched from elevated dock-yards, &c. What a busy scene is a great sea-port river, during the rising and falling of the tide—with the thousands of people along its banks, borrowing assistance in their various occupations!

Winds are produced chiefly by the fluid atmosphere seeking its level, in obedience to the attraction of the earth, after the action of disturbing causes, such as the heat of the sun, &c. They help man in the important business of *navigation;* they turn his windmills, &c.

The Currents of rivers, are water constantly moving along slopes, that is, regaining its level, in obedience to the earth's attraction. Watermills and inland navigation are among the advantages which they afford to man.

All falling and pressing bodies exhibit attraction in its simplest form.

Repulsion—is instanced in *explosion, steam,* the action of *springs, &c.*

Explosion of gunpowder is repulsion among the particles when assuming the form of air.

Steam, by the repulsion among its particles, moves the piston of the steam-engine. In our days it performs half the labour of society.

Accidental explosions of fire-damp, or hydrogen, in mines, and the tremendous evolutions of elastic fluid in volcanoes and earthquakes, are other instances of the same class.

All *elasticity*, as seen in springs, collision, &c. belongs chiefly to repulsion.

A spring is often, as it were, a reservoir of force, kept ready charged for a purpose; as when a gunlock is cocked, a watch wound up, &c.

It will be remarked, with respect to many of the phenomena now and hereafter to be mentioned, that it is not the original attraction or repulsion which man uses as his servant, but the momentum gradually accumulated in masses by such attraction or repulsion.

Electrical, galvanic, magnetical, and *optical* phenomena, are also in great part peculiar attractions and repulsions, as will be seen in the chapters devoted to them. And even the *actions of animals*, so infinitely varied, are produced simply by the shortening of the fleshy threads called muscular fibres, owing to the mutual *attraction* of their component particles;—just as the varied motions of a telegraph, or of a ship's yards, are produced by the shortening of certain ropes of connexion.

However closely allied the last-mentioned particular attractions and repulsions may be to the general attraction and repulsion formerly treated of, it is found convenient to consider them apart, and they are accordingly reserved for future chapters.

In the remarkable phenomena of nature and art, all caused, as now shown, by attraction and repulsion, these forces do not operate by a single impulse, but through a repetition of impulses, or a continued action, of which the effect is gradually accumulated in the inertia of matter. Thus all great velocities and momenta are the terminations of an accelerated motion.

Meteoric stones, falling from great heights, bury themselves deep in the earth by the force of their gradually acquired velocity.

When the wood-cutters among the Alps launch an enormous tree from high on the mountain side, along the smooth wooden trough or channel prepared for it, and in fewer minutes than it traverses miles, it is seen plunging into the lake below; it acquires its frightful velocity, not at once, but through the action of gravity continued during the whole of its descent.

The shock or blow of the ram of a pile-engine, is not the effect of momentary attraction between it and the earth, but of that attraction accumulating motal inertia or power, during the descent of the ram through a space of twenty or thirty feet.

A common hammer, in its instantaneous shock, has the condensed effect of the arm and of gravity, as accumulated through its whole previous course; and when a powerful blow is intended, the hammer, or hatchet, or club, or fist in boxing, is lifted high and carried far back, that there may be time and space for imparting greater power.

Many actions of the inferior animals are illustrative of the same truth, and prove their experimental or instinctive acquaintance with it.

Sea birds carry shell-fish up into the air, and drop them, on smooth stones, to break them, and to obtain the food. It is related in Grecian story, that a bird once mistook the venerable bald head of a sage meditating on the sea-shore for a smooth stone, and by the same act killed an oyster and the philosopher.

There are some long-necked birds, that fight and kill their prey by a blow of their beak. They draw back the head, bending the neck like a swan or serpent, and then dart it forward, with a continued effort, until the strong wedge-like beak reaches its destination, almost with the velocity of a pistol bullet. A snake in darting its fangs at an enemy passing swiftly across its coil, has missed its aim and inflicted a mortal wound on its own flesh.

Bulls, rams, and goats, in fighting, alternately recede and run at each other that the shock may be great when the foreheads meet.

A horse in kicking, from the great length of his leg, and the consequent space through which he can be adding velocity to his foot, sends it at last against the object almost like a cannon shot.

A bow-string propelling an arrow, follows it through a considerable space, and hence the great velocity at last produced.

A sling gives to the hand the power of adding velocity to the stone through a long path; for the hand moves in a small circle while the stone moves in a larger, and the hand being kept always in advance of the stone, pulls at it without intermission, however quickly moving.

The battering rams of the ancients allowed those about them to accumulate in them the efforts of many hands, and of a considerable duration of action, so as to give at last one great and sudden shock.

Even the gentle action of the human breath, exerted for a time on a pea or small hard ball of clay, while passing through a long smooth tube, gives a velocity which will inflict a sharp and painful stroke on a distant animal. In Borneo and others of the Eastern Islands, poisoned arrows are thrown in this way with great force and precision.

The action of gunpowder on bullets, although appearing so sudden, is still not an instantaneous, but a gradual, and therefore accelerating action; and accordingly we find the effect to depend much on the length of the piece along which the force pursues the ball. A small fast-sailing vessel with a single long gun has often compelled a very superior vessel, whose guns were shorter, to yield.

For the same reason that all great velocities require continued action or repeated impulse to produce them, so do they also to destroy them, the inertia of motion and of rest being exactly equal.

A vast mass of rock suspended like a pendulum, and allowed to sweep down its curve from a considerable elevation, would arrive at the bottom like a battering ram, with force sufficient to shake a thick wall or rampart to its foundation. The continued action of gravity would have given this force, and if, instead of the solid resistance now supposed, and which would not be sufficient to take the whole momentum away, the mass were merely allowed to continue its course as a pendulum, and to ascend on the other side, the continued action of gravity then opposing its motion, would bring it to powerless rest again, by the time when it had reached an elevation equal to that from which it fell.

Soft air expanding gives gradually the death-carrying velocity to the cannon ball; and soft air, or cotton, or wool, resisting in a close strong tube,—if the bullet could be directed exactly into it—would again gradually annihilate the motion. Were the attempt made, however, to stop the ball suddenly, by a block of the hardest granite, the block would instantly be riven by its force.

Bales of cotton or thick yielding cork attached round a ship will receive cannon balls, and bring them to rest, without themselves suffering much: while the naked firmer side of the ship would be penetrated. The cotton or cork offers an increasing resistance through a considerable space, while the oak opposes its hard front at once, and must instantly suffice or be destroyed. A hard body, that it may at once destroy such a motion as we are supposing, must be able to oppose as much force in perhaps the space of one-hundredth of an inch, that is, in the extent to which its elasticity will let it yield without breaking, as the moving cause gave, through a much greater space (a plate of steel will thus oppose a pistol-bullet;) and when it cannot do this, it must be broken or penetrated by the moving body. It is to be remarked, however, that the continued opposition of a thick mass of wood, stone, or earth, to an entering bullet, brings it to rest at last just as any elastic unbroken opposition would. Gunners have ascertained the exact depth in each substance to which a ball will penetrate; and they call buildings *bomb* or *ball-proof*, which have a thickness or depth exceeding this.

A hempen or silken rope supporting the scale of a weighing beam: would resist a greater weight falling into the scale than would be resisted by an iron chain, even stronger than the rope for the purpose of bearing a quiescent weight: because the hemp or silk would yield by its elasticity, and continue its resistance through a considerable space and time, and thus would at last gradually overcome the momentum: while the iron, by not yielding, either would require to be strong enough to stop the mass suddenly, or would break.

Yet, for the same reason that iron is weakest in the last case, it is stronger than hemp or rope when used as a cable for a ship, to withstand the sudden force of waves, because the chain by its weight hangs as a curve or inverted arch in the water, while the rope being nearly of the weight of water, is supported by it and becomes almost a straight line from the anchor to the ship; and when a great wave dashes against the ship, the straight rope can only yield by the elasticity of its material, and comparatively, therefore, a little way; but the bent chain will yield until it be drawn nearly straight, and by this greater latitude of yielding, and consequent length of resistance, it will withstand a greater shock.

A heavy ship moving quickly with the tide or wind, could not be stopped instantly by a short chain of any magnitude:—if the attempt were made to destroy at once so vast a momentum, something would certainly give way; but a rope of very moderate size, kept tight between the shore and the ship, and from time to time allowed to slip a little round a wooden block, when the tightness threatened its breaking, would accomplish the end very soon and easily.

The following are further proofs that forces are to be measured as much by the time or space through which they act, as by their difference of intensity or momentary power.

A door standing open, and which would yield readily on its hinges to the gentle push of a finger, is not moved by a cannon ball piercing through it. Now the ball really overcomes the whole force of cohesion among the atoms of tough wood : but that force is allowed to act or resist for so short a time, owing to the rapid passage of the ball, that it is not sufficient to affect the inertia of the door, in a degree to produce sensible motion. The cohesion of the circle in the door, cut out by the ball, would have borne a weight of more than a hundred pounds laid quietly upon it, but (supposing the bullet to fly twelve hundred feet in a second and the door to be one inch thick) being only allowed to act for the 14,400th part of a second, its influence is not perceived. The following are other examples of the same kind.

A leaden bullet pressed slowly against a pane of glass breaks it irregularly, where the strength happens to be least; but the same bullet shot at it from a pistol, makes only a small round hole. It has been amusingly said of such a case, that the particles struck and carried away, have not time to warn their neighbours of what is happening.

A cannon ball, having very great velocity, passes through a ship's side, and leaves but a little mark; while one with less speed splinters and breaks the wood to a considerable distance around. A near shot thus often injures a ship less than one from a greater distance.

A sheet of paper, standing edgeways on a table, is not driven down by a pistol ball fired through it.

The truth at present under consideration explains, with respect to gun-shot wounds, why a man often remains ignorant for a time of his misfortune, and why a rapid bullet only kills the parts which it touches, while a spent ball may bruise and injure all around. In many cases of injury attributed to the *wind of a ball*, the ball itself has really touched the part.

A circular plate of soft iron, made to turn with extreme rapidity, cuts through the hardest steel file, as a knife cuts through a carrot. In cases where a soft powder suffices to polish a hard body, it acts partly like this plate, by the motion or velocity given to the wearing particles.

A man lying down and receiving the blow of a great hammer on his chest, would be destroyed by it; but if a heavy anvil be first laid upon the chest, and the blow be then received upon the anvil, the man bears it with impunity. Here the quantity of motion in the hammer, being diffused through the great mass of the anvil, produces but a trifling velocity, which the elasticity of the chest, in its slow yielding, easily overcomes.

"There is no motion or action in the universe, without a concomitant and opposite action of equal amount." (*See the analysis.*)

This truth has otherwise been expressed—"action and re-action are equal and contrary."—It is clear that if no action or movement takes place on earth but in consequence of either attraction or repulsion,—and this has now been shown—there must always be two objects or masses concerned, and each must be *attracted* or *repelled* just as much as the other, although one will have less velocity as it may itself be greater or fixed to a greater mass.

If a man in one boat pull at a rope attached to another, the two boats will approach. If they be of equal size and load, they will both move at the same rate, in whichever of the boats the man may be; and if there be a difference in the sizes, and resistances, there will be a corresponding difference in the velocities, the smaller boat moving the fastest.

A magnet and a piece of iron attract each other equally, whatever disproportion there is between the masses. If either be balanced in a scale, and the other be then brought within a certain distance beneath it, the very same counterpoise will be required to prevent their approach, whichever be in the scale. If the two were hanging near each other as pendulums, they would approach and meet: but the little one would perform a greater part of the journey, in proportion to its littleness.

A man in a boat pulling a rope attached to a large ship, seems only to move the boat: but he really moves the ship a little, for a thousand men in a thousand boats, pulling simultaneously in the same way, would make the ship meet them half way.

A pound of lead and the earth attract each other with equal force; but that force makes the lead approach sixteen feet in a second towards the earth, while the contrary motion of the earth is of course as much less than this as the earth is weightier than one pound, and is therefore unnoticed. Strictly, however, it is true, that even a feather falling lifts the earth towards it, and that a man jumping kicks the earth away.

A spring unbending between two equal bodies, throws them off with equal velocity; if between bodies of different magnitudes, the velocity is greater in the smaller body, and in exact proportion to the smallness.

On firing a cannon, the gun recoils with as much motion or momentum in it as the ball has; but the momentum in the gun being diffused through a greater mass, the velocity is small, and easily checked.

The recoil of a light fowling-piece will hurt the shoulder, if the piece be not held close to it.

A ship in chase, by firing her bow guns, retards her motion; by firing from the stern she quickens it.

A ship firing a broadside, heels or inclines to the other side.

A vessel of water suspended by a cord hangs perpendicularly: but if a hole be opened on one side, so as to allow the water to jet out there, the vessel will be pushed to the other side by the re-action of the jet, and will so remain while it flows. If the hole be oblique, the vessel will turn round constantly.

A vessel of water placed upon a floating piece of plank, and allowed to throw out a jet, as in the last case, moves the plank in the opposite direction.

A steam-boat may be driven by making the engine pump or squirt water from the stern, instead of, as usual, moving paddle wheels. There is a loss of power however in this mode of applying it,as will be explained under the head of "Hydraulics."

A man floating in a small boat, and blowing strongly with a bellows towards the stern, pushes himself onwards with the same force with which the air issues from the bellows pipe.

A sky-rocket ascends, because, after it is lighted, the lower part is always producing a large quantity of aeriform fluid, which, in expanding, presses not only on the air below, but also on the rocket above, and thus lifts it. The ascent is aided also by the recoil of the rocket from the part of its substance, which is constantly being shot downwards.

He was a foolish man who thought he had found the means of commanding always a fair wind for his pleasure-boat, by erecting an immense bellows in the stern. The bellows and sails acted against each other, and there was no motion: indeed in a perfect calm, there would be a little backward motion, because the sail would not catch all the wind from the bellows.

A man using an oar, or a steam-engine turning paddle wheels, advances exactly with the force that drives the water astern.

A swimmer pressing the water downwards and backwards with his hands, is sent forwards and upwards with the same force by the re-action of the water.

And a bird flying, is upheld with exactly the force with which it strikes the air in the opposite direction.

A man pushing against the ground with a stick, may be considered as compressing a spring between the earth and the end of his stick, which spring is therefore pushing up as much as he pushes down; and if, at the time, he were balanced in the scale of a weighing beam, he would find that he weighed just as much less as if he were pressing with his stick.

Thus an invalid, on a spring plank or chair, who causes his body to rise and fall through a great range, by a trifling downward pressure of his hand on a staff or on a table, and thus obtains the advantage of almost passive exercise, is really lifting himself while he presses downward.

When a child cries, on knocking his head against a table or a pane of glass, it is common to tell him, and it is true, that he has given as hard a blow as he has received; although his philosophy, attending chiefly to results, probably blames the table for his head hurt, and his head for the glass broken.

The difference of momentum acquired in a fall of one foot or of several, is well known: the corresponding intensities of re-action are unpleasantly experienced by a man who, in sitting down, is quietly received into a chair, or who unexpectedly reaches the floor where he supposed a chair to be.

What motion the wind has given to a ship, it has itself lost, that is to say, the ship has re-acted on the moving air: as is seen when one vessel is becalmed under the lee of another.

When a billiard ball strikes directly another ball of equal size, it stops, and the second ball proceeds with the whole velocity which the first had:—the action which imparts the new motion here being equal to the re-action which destroys the old. Although the transference of motion, in such a case, seems to be instantaneous, the change is really progressive, and is as follows. The approaching ball, at a certain point of time, has just given half of its motion to the other equal ball, and if both were of soft clay, they would then proceed together with half the original velocity; but, as they are elastic, the touching parts at the moment supposed, are compressed like a spring between the balls, and by then expanding, and exerting force equally both ways, they double the velocity of the foremost ball, and destroy altogether the motion in the other.

If a billiard ball be propelled against the nearest one of a row of balls equal to itself, it comes to rest as in the last case described, while the farthest ball of the row darts off with its velocity, the intermediate balls having each received and transmitted the motion in a twinkling, without appearing themselves to move.

Further illustrative of the truths, that action and re-action are equal and contrary, and that in every case of hard bodies striking each other, they may be regarded as compressing a very small strong spring between them, we may mention, that when any elastic body, as a billiard ball, strikes another ~~larger than~~ eit itself, and rebounds, it gives to that other, ~~not only~~ all the motion which it originally possessed, ~~but an additional quantity, equal to~~ by that with which it recoils—owing to the equal action in both directions of the repulsion or spring which causes the recoil. When the difference of size between the bodies is very great, the returning velocity of the smaller is nearly as great as its advancing motion was, and it gives a momentum to the body struck, nearly double of what it originally itself possessed. This phenomenon constitutes the paradoxical case of an effect being greater than its cause, and has led persons, imperfectly acquainted with the subject, to seek from the principle, a *perpetuum mobile*. A hammer rebounding from an anvil has given a blow of nearly double the force which it had itself, for the anvil both felt its approach, and, equally with itself, was affected by the repulsion which caused its return.

Many more interesting facts might be adduced as examples of the equal action and re-action between bodies, but these will suffice.

This second section of the work, then, has explained the nature of INERTIA in matter, and has shown that the infinitely varied phenomena of motion, which the universe exhibits, are only *attraction* and *repulsion*, acting on *inertia* under diversified circumstances.—And such is the sublime simplicity of the whole scheme of nature.

APPENDIX

TO PART I.—SECTION II.

BY THE AMERICAN EDITOR.

THE attentive perusal of the preceding section, will prepare the reader to understand the following propositions.

Definitions.

Prop. 1.—When a body is successively changing its place it is said to be in *motion*, p. 78.

The idea of motion involves those of *space*, *time*, *velocity*, *direction*, the quantity of matter and momentum.

Prop. 2.—The *space described* is the distance passed over by a body during its motion; and is measured by the number of units of length, as a foot, a yard, a mile, &c. contained in this distance.

Prop. 3.—The *time* consists of a certain number of units of time adopted as its measure, as a second, a minute, &c. which have elapsed during the motion of a body.

Prop. 4.—The *velocity* of a body is the rate at which it moves, or the number of these assumed units of space that it passes over during the assumed unit of time.

All the above measures may be represented graphically by lines that are proportioned to them. p. 99.

Prop. 5.—The *direction* of a body may be straight or curved; when straight or rectilineal, it is the angle which its path makes with any straight line in the same plane, adopted as an axis; when the path of a body is a curve, its direction at any point is the angle which the tangent to the curve at the point, makes with the fixed axis.

Prop. 6.—The momentum of a body is its quantity of motion, both the mass and velocity being taken into consideration, and its proper measure is the product of the mass into the velocity, *p.* 93, 94, 95, 96.

Prop. 7.—A body is said to have a *uniform motion* when its velocity remains constant, that is, when it describes equal spaces in equal successive intervals of time. p. 86,

Prop. 8.—Every motion that is not uniform is said to be *varied*, and is called *accellerated* or *retarded* as the velocity increases or decreases.

Prop. 9.—When the velocity constantly increases or decreases in the direct ratio of the time, that the body has been moved, the motion is said to be *uniformly accellerated* or *retarded*. *p.* 102. 104.

Prop. 10.—Whatever is capable of producing or destroying the motion of a body is called *force*.

Prop. 11.—A force that produces its effect instantaneously, and then ceases to act is called an impulsive force.

Prop. 12.—A force that acts continually and equally is termed a *constant force*.

Prop. 13.—When the constant force acts in lines directed towards a single point or centre, it is called *centripetal*, and the path of the body its *orbit*, *p.* 89.

Prop. 14.—That part of the impulsive force which tends to make a body move directly from the centre, is termed the *centrifugal force*, *p.* 89.

Prop. 15.—A force that is capable of destroying motion without being able under any circumstances to produce motion, is termed a *passive force*.

Prop. 16.—The state of rest produced by the action of opposite forces is termed equilibrium.

Prop. 17.—When a body is struck, its particles yield to the impulse, and the form of the body is changed. When the body possesses the inherent power, when thus changed of restoring its form, it is said to be *elastic;* when it has not this power, it is called non elastic, *p.* 115.

Prop. 18.—A body oscillating below a point to which it is in any way attached is termed, a pendulum, *p.* 105.

Laws of Motion.

Prop. 19.—1st. If a body be at rest it will continue at rest, and if in motion, it will continue to advance uniformly in a right line, unless compelled to change its state by some external force, pp. 79. 86. 88.

Prop. 20.—2d. The motion of a body is in the direction of the force that produces it and is proportional to that force, pp. 93. 97.

Prop. 21.—3d. Action and re-action are always equal and opposed to each other; or when a body communicates motion to another, it loses of its own momentum as much as it gives to the other body, p. 96.

Of Impulsive force and Rectilinear motion.

Prop. 22.—The effect of an impulsive force is to produce *uniform rectilinear motion, p.* 86.

For during the moment of its action on any body it must set it in motion with a certain velocity; and by the first law of motion the body must continue to advance in a straight line with that velocity.

Prop. 23.—In rectilinear motion the *space* is as the velocity multiplied into the time.

For if a body move with the velocity of 3 feet per second, it is evident, that it will move over 6 feet in 2 seconds, i. e. 3×2; and 9 feet in 3 seconds, i. e. 3×3, and 12 feet in 4 seconds, &c. &c.

Prop. 24.—The *time* is as the space divided by the velocity.

For if a body passes over 12 feet, for instance, when its velocity is 3 feet per second, it is evident that in order to find the number of seconds, which the body has employed in passing over 12 feet of space; we need only divide 12 by 3, (i. e. the space by the velocity) and the quotient 4, is the *time* sought.

Prop. 25.—The *velocity* is as the space divided by the time.

For if a body move over 12 feet in 4 seconds its velocity is evidently 3 feet per second or 12÷3.

The velocities of two bodies may be compared, in the same manner: the velocities of two bodies A and B, for instance, of which A moves over 54 feet in 9 seconds, and B, 96 feet in 6 seconds; their velocities will be as 6 (54÷9) to 16 (96÷6.*)

---

[*] For the benefit of those who are acquainted with algebra, we subjoin the fol-

Of a constant force and uniformly accelerated motion.

Prop. 26.—The effect of a constant force acting upon a body, is to produce in it a uniformly accelerated motion, p. 102.

For since the effect of force is to produce velocity, a constant force must in successive instants of time afford continual and equal additions to the velocity of the body it has set in motion; that is the velocity will increase in the direct ratio that the body has been moving, which is the definition of *uniformly accelerated motion.*

Prop. 27.—In uniformly accelerated motion the space described is as the square of the time, pp. 103, 104.

Thus it is found by experiment that if a body move with a gradually and constantly increasing velocity that would carry it through a mile in one minute; that at the end of this time it has acquired such a velocity as would carry it through two miles the next minute, if the force that communicated its motion ceased to act at the end of the first minute; but if the force continues to act, it acquires a velocity that would carry it over an additional mile so that it will pass over three miles the second minute or four miles in two minutes. At the end of the second minute it has acquired a velocity that will carry it over double the space in the third minute that it moved over in the first two minutes or a velocity of 8 miles in 2 minutes or 4 miles a minute. But the force still continuing to act, it will move a mile farther or 5 miles in the third minute. Hence if a body acted upon by a continued force move a mile the first minute, it would move 3 miles the second, 5 the 3d, 7 the 4th, 9 the 5th, &c.

Thus the spaces described in successive equal parts of time, by uniformly accelerated motion, are always as the odd numbers 1, 3, 5, 7, 9, &c. and consequently the whole spaces are as the squares of the times or of the last acquired velocities. For the continued addition of the odd numbers yields the squares of all numbers from unity upwards. Thus 1 is the first odd number and the square of 1 is 1; 3 is the second odd number and this added to 1 makes 4, the square of 2;—5 is the third odd number and this added to 4 makes 9 the square of 3; and so on for ever. Since therefore the times and velocities proceed evenly and constantly as 1, 2, 3, 4, &c. but the spaces described in equal times are as 1, 3, 5, 7, &c. it is evident that the space described,

---

lowing equation, which expresses all the circumstances of uniform motion.

Let t = the time of motion,

s = the space described in the time t,

v = the velocity:

Then, $s = vt$ from which we obtain

$$v = \frac{s}{t}$$

$$\text{and } t = \frac{s}{v}$$

In 1 minute will be - - - 1 = Square of 1
In 2 " " " - - 1 + 3 = 4 = " 2
In 3 " " " - 1 + 3 + 5 = 9 = " 3
In 4 " " " 1 + 3 + 5 + 7 = 16 = " 4 &c.

Spaces described in ~~1 minute~~ each minute

Of Gravity.

Prop. 28.—The force which causes bodies to fall to the earth is of the kind named constant and is called gravity, p. 102.

Prop. 29.—The direction of gravity is in lines perpendicular to the earth's surface.

Prop. 30.—The force of gravity is directly proportional to the mass of the body.

For however small the parts into which we divide a body, we find them all affected by gravity, since this force must act upon all the particles of a body.

Hence in an unresisting medium all bodies setting out from a state of rest, fall through the same space in the same time, because the force of gravity acting upon them increases in proportion to the mass to be moved.

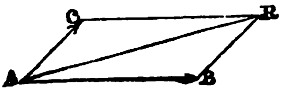
Prop. 31.—The force of gravity decreases, as the square of the distance from the attracting body increases.

This is proved by astronomical observations.

Motion produced by joint forces.

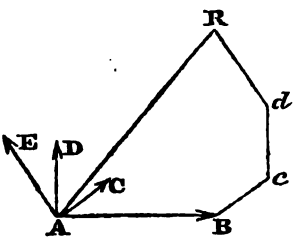
Prop. 32.—When a body is acted upon at the same moment by a pleurality of forces, each of these forces, produces its full effect; and the place of the body at the end of any given time is the same as it would have been if the forces had acted in succession each during that time, pp. 97, 98, 99.

Fig. 1.



Thus let A B represent the direction of a force that would move a body A the distance from A to B in a certain interval of time, (a second for example) and AC, the direction of a force that would propel the same body from A to C in the same interval of time. Suppose the first force acted alone, it would move the body from A to C in one second; if the force AC, then acted at B, by drawing B R equal and parallel to AC, B R will represent the direction and velocity of the force AC, and R the position in which the body would be in at the end of the second interval of time. Unite A and R and the line AR will represent the course of the body A if acted upon at the same moment by the two forces A B and AC and R the position of the body at the end of the first interval of time.

Fig 2.



In the same manner the action of any number of forces may be represented. Thus let AB, AC, AD, AE, represent the separate effects of four different forces acting in the same plane, capable of moving a body the distances AB, AC, AD, AE, in a given interval of time. Draw Bc, cd, dR, equal and parallel to AC, AD, AE respectively, and join AR. ABcd R, will represent the path of the body if these forces had acted successively each during one interval of time, and AR the path of the body if they all act together, and R the position of the body at the end of the first interval of time.

Prop. 33.—The line A R in the figures given to illustrate the preceding proposition represents the direction and measure of a single force, equivalent to all the others in each figure; and hence the process by which it is determined is called the *compositor of forces*, pp. 97, 98, 99, 100.

Prop. 34.—Any force may be decomposed into any number of other forces, that shall be equivalent to it, by the reverse of the foregoing operation. This process is called the *Resolution of forces*, p. 100.

Thus the force AR fig. 1. may be separated into two forces AB, AC, and the force AR fig. 2 into four forces AB, AC, AD and AE.

Prop. 35.—When the forces act in the same right line, we have only in order to ascertain the spaces described by their combined action, to add or substract the spaces which would be described by their separate action, according as these forces act, in the same or opposite directions.

Equilibrium.

Prop. 36.—A body acted upon by a pleurality of forces, will remain at rest, or *in equilibrio*, when if these forces were supposed to act in succession, each during the same interval of time, the body would arrive at its point of departure.

The simplest and most evident case of *equilibrium* is that in which a body is acted upon by two equal and opposite forces.

On the joint action of an impulsive and a constant force.

A. *When these forces act in the same right line.*

Prop. 37.—When the forces act in the same direction, the place of the body at the end of any given time, may be determined, as in the problem of the composition of forces, by supposing, first that the impulsive force acts during that time, and then that the action of the constant force commences and acts alone during the same time; the spaces added together will give the space passed over by the joint action of these forces during the assumed time.

Prop. 38.—When the forces act in opposite directions, the place of the body may be ascertained by a similar process; in this case however the spaces are to be substracted one from the other, pp. 104, 105.

When a constant force is acting in a direction contrary to that of a moving body set in motion by an impulsive force, the retardation that the former produces may be determined by comparing the motion with that of a body moved by the same force.

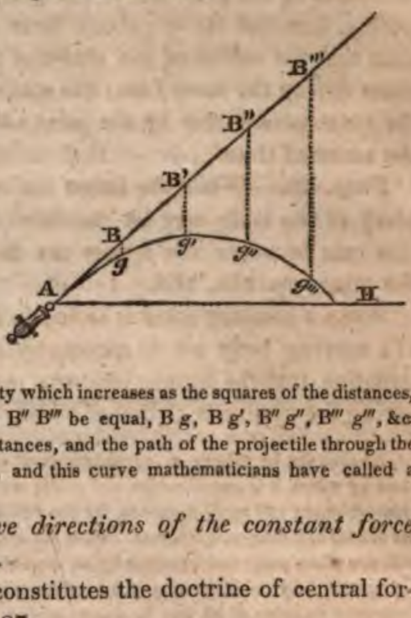
The degrees by which an ascending body loses its motion, are the same as those by which it is again accelerated at the same points, when it has acquired its greatest height and again descends, for the velocities at the corresponding parts of the ascent and descent are equal. Thus we may calculate to what height a body will rise when projected upwards by an impulsive force, gunpowder for instance, and retarded by the force of gravity. Since the force of gravitation produces or destroys a velocity of 32 feet in every second, a velocity of 320 feet will be destroyed in 10 seconds; and according to what has been premised a body will fall in 10 seconds through a hundred times 16 feet or 1600 feet, which is therefore the height to which a velocity of 320 feet in a second will carry a ball projected, without resistance from other cause than gravity, in a vertical direction, *p.* 104.

B. *When these forces act in different directions.*

* *When the successive directions of the constant force are parallel.*

Prop. 39.—If the constant force be that of gravity, the successive directions of which are assumed to be parallel, the investigation of the effects produced, constitute the doctrine of projectiles; a projectile being a body thrown in any direction by an impulsive force and at the same time acted upon by the force of gravity, pp. 111, 112, 113.

Prop. 40.—The place of a projectile at the end of any given time, may be determined, as in the problem of the composition of forces, by supposing first that the impulsive force alone has acted during that time, and then that the action of gravity commences, and acts alone during the same time.

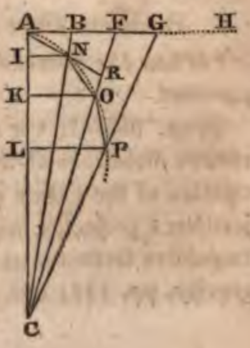


Thus let A H represent a horizontal plane, and AB, the initial direction and velocity of a body projected from the point A in the same plane. If the impulsive force alone acted on the body it would describe the path $AB\,B'\,B''\,B'''$ &c, with uniform velocity. But as the force of gravity acts from the moment of projection, the body will be drawn downwards from the line AB''' so as to be found after the successive intervals of time, at the points $g\ g'\ g''$, &c. and as the force of gravity produces a velocity which increases as the squares of the distances, if the distances AB, $B\,B'$, $B'\,B''$, $B''\,B'''$ be equal, $B\,g$, $B\,g'$, $B''\,g''$, $B'''\,g'''$, &c. will be as the squares of these distances, and the path of the projectile through the points $g\ g'\ g''\ g'''$ will be a curve, and this curve mathematicians have called a parabola.

* * *When the successive directions of the constant force tend to a common centre.*

Prop. 41.—This case constitutes the doctrine of central forces, see prop. 13. pp. 86, 87.

Prop. 42.—The place of the body at the end of any given time may be determined here also by the problem of the resolution of forces.



Thus suppose, A represent a body impelled towards H with such a force as by itself would enable it to run over the equal spaces AB, BF, FG, &c. in equal portions of time: suppose likewise that it is acted upon the same time by a constant force which would enable it to pass over the unequal spaces AI, IK, KL, &c. in the same equal portions of time. It is evident, that the joint action of both these forces would compel the body A to pass over the curvilinear path A N O P, &c. Through B draw the line BC, (viz. in the centre of the attraction;) through I drawn IN parallel to AB; and at the end of the first portion of time the body will be found at N.

whence it would proceed in the straight direction NR, (by the first law of motion) if the constant force then ceased to act. But as this force continues to act, the body at the end of the second portion of time will be found in O; for the like reason, at the end of the third portion of time it will be found in P and so on. The course then AN OP, is not straight but consists of the lines AN, NO, OP, forming certain angles with each other. Now it will not be difficult to conceive that, because the attractive force acts not by intervals but constantly and unremitedly, the real path of the body must be a polygonal course, consisting of an infinite number of sides: or more justly speaking, a continuate curved line, which passes through the points A, N, O, P, &c. as is shown by the dotted line.

Prop. 43.—Should the action of the centripetal force cease at any instant, the body could proceed straight forward, p. 60.

The portion of the impulsive force by which this is effected is called the *centrifugal*, prop. 14.

Prop. 44.—Whilst the distance from the centre remains unchanged, as when the body moves in a circular orbit, the centripetal and centrifugal, forces are equal.

Laws of Central forces.

Prop. 45.—When bodies revolve in equal circles, their centrifugal forces are proportional to the squares of their velocities.

Prop. 46.—When two bodies revolve with equal velocities at different distances, the centrifugal forces are inversely as the distances.

Consequently (prop. 45, 46.) the centrifugal forces are in all cases, directly as the squares of the velocities, and inversely as the distances.

Prop. 47.—When two bodies revolve in equal times at different distances, their centripetal forces are simply as their distances.

In general the centripetal forces are as the distances directly and as the squares of the times of revolution inversely.

Prop. 48.—When the forces vary inversely as the squares of the distances, as in the case of gravitation, the squares of the times of revolution are proportional to the cubes of the distances.

Thus if the distance of one body be four times as great as that of another, the cube of 4 being 64, which is the square of 8, the times of its revolution will be S times as great as that of the first body.

Prop. 49.—Where the orbit deviates more or less from a circular form, a right line joining the revolving body and its centre of attraction, always describes equal areas in equal times, and the velocity of the body is therefore always inversely as the perpendicular drawn from the centre to the tangent.

. *Prop.* 50.—To propel a body in an eliptical orbit, the force directed to its focus must be inversely as the square of the distance.

This is proved by astronomical observations but we have no other proof of it.

The motion of the planets round the sun in the solar system is governed by the laws of central forces, the centripetal force in this case being that of gravity.

On the joint effect of active and inactive forces.

A. *When they have opposite directions.*

Prop. 51.—The effect of passive forces is to restrain and modify the action of other forces so as to confine the motion of a body to a particular course or path, and the direction of the passive force affecting a body at any moment is the line perpendicular to that part of this path at which the body is found at this moment. If the direction of the active force be also perpendicular to this path, the body must evidently remain at rest, since no part of this force can be resolved into the direction of the path in which alone the body can move.

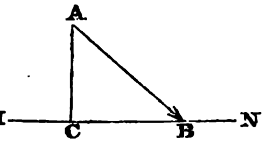
B. *When they have different directions.*

General rule.

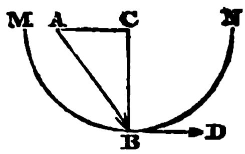
Prop. 52.—Resolve the active force into two, one perpendicular, and the other a tangent to the path of the body, the effect of the former force will be entirely destroyed (*prop.* 51) and the body will advance by the latter alone.

* *On the motion of a body impelled obliquely against a place.*

Prop. 53.—Let M N, represent the plane and A B, the direction and velocity from the impulsive force, resolve A B, into the forces A C perpendicular to the plane and C B in its direction, then by the general rule (*prop* 52.) the body will move along the plane with a velocity of which C B is the measure.



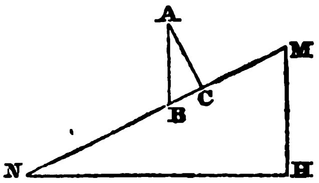
* * *On the motion of a body impelled obliquely against a curved surface.*



Prop. 54.—Let M N, represent the curve and AB the direction and velocity from the impulsive force. Resolve AB into two forces C B perpendicular to the curve at B and B D (equal to AC) a tangent to the curve at the same point. Then B D will represent the velocity at the point B.

Prop. 55.—If the curve be interrupted at any point, or change the direction of its concavity the body will advance with its last velocity in a tangent to the curve at that point.

* * * *On the descent of a body along an inclined plane.*



Prop. 56.—Let M N represent an inclined plane and AB (perpendicular to the horizontal base H N) the force of gravity, as measured by the distance which it would cause a body to descend in the first second of time. Resolve AB into two, AC perpendicular to the plane and CB in its direction, then the body will be urged down the plane by a constant force measured by CB.

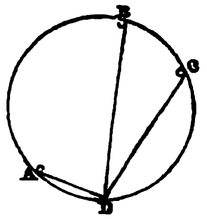
Laws of the descent of bodies down inclined planes.

Prop. 57.—1st. The motion of a body down an inclined plane is uniformly accelerated.

Prop. 58.—2d. The velocity acquired is proportional to the perpendicular descent, so that a body falling from M to H has the same velocity at H as one descending the whole length of the plane at N.

Prop. 59.—3d. The times of descent down planes of the same height are as their lengths.

Prop. 60.—4th. The times of descent down all planes which are chords drawn to the lowest point of the same circle, are equal.



Thus if the balls, A, B, C, be placed at the different points of the circle and suffered to descend at the same instant along as many planes which meet at the lowest point of the circle, they will arrive there at the same time.

Or it may be enunciated in the following terms, the times of descent down all the chords drawn from the same point or circumference of a circle will be the same.

This will be made evident by supposing the above figure inverted, D being made the upper point and the balls allowed to fall from that point to A, B, and C.

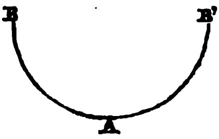
* * * * *On the descent of a body down a vertical curved line.*

Prop. 61.—The times of descent down the chords of different circles are to each other as the square roots of their diameters.

Prop. 62.—If a body fall from a state of rest down a vertical curve, the velocity acquired is equal to that which it would have by falling through the same perpendicular height.

For if the curve be considered as made up of an infinite number of contiguous planes, it is evident that the angle of inclination of any two of these adjacent planes is infinitely small, or nothing and consequently there is no velocity lost by a change of direction in passing from one to the other. Therefore as the effect of gravity is not impeded the truth of the proposition becomes evident.

Prop. 63.—If a body be projected up a curve, the perpendicular height to which it will rise is equal to that through which it must fall to acquire the velocity of projection. For the body in its ascent will be retarded in the same degree that it was accelerated in its descent.



Thus let B A B′ be a curve in which the lowest point is A, and the parts AB, AB′ are similar ; a body in falling down B A will acquire a velocity that will carry it to B′, and since the velocities in all equal altitudes in the ascent and descent are equal, the times of ascent and descent are equal.

The foregoing proposition is equally true whether the body actually move over a solid surface or be retained in its path by a string which is in every part perpendicular to it.

Of the simple Pendulum.

Prop. 64.—The simple pendulum is conceived to be a mere material point suspended by an imponderable and inextensible thread, p. 105.

Prop. 65.—If the simple pendulum vibrate through very small arcs, these may without sensible error, be conceived to coincide with their chords, and we may derive from this consideration the following theorems.

1st. As the times of descent of a body down different chords of the same vertical circle are equal (*prop* 60.) the vibrations of the same pendulum, although performed through unequal arcs, will be very nearly equal, p. 106.

2d. The times of vibrations of different pendulums will be to each other as the square roots of the lengths of these pendulums, or, which is the same thing, that their lengths are proportional to the squares of the times of vibration, p. 107.

The times of descent down the chords of different circles are the same as would be occupied in descending vertically through their diameters and are consequently proportional to the square roots of these diameters.

Of the impact of Bodies.

Prop. 66.—When a body in motion strikes directly another body, it always communicates motion to the second body, and loses part of its own, and from the third law of motion it is evident that the momentum gained by the second body is exactly equal to that lost by the first.

Prop. 67.—When one non-elastic body strikes against another, the two bodies will move on together, since there is no force to separate them ; and as one of the bodies gains all the momentum which the other loses, the momentum after impact will be equal to the sum of the momenta before impact.

Prop. 68.—When an elastic body strikes against another, the second is impelled forward with double the momentum, which it would have received under the same circumstances if non-elastic.

For at the moment of impact the form of the body struck is changed by a force equivalent to the momentum which it receives from the striking body, and if this body be perfectly elastic, its form will be restored to it by a force exactly equal to that by which it was changed. and this force (which we have just seen to be equal to the original impulse,) will be exerted in driving the body forward. The body thus receives besides its original impulse the equal force of the re-bound.

Prop. 69.—The striking body when elastic, is also acted upon by the re-bound, and loses twice as much momentum as it would have lost if non-elastic.

In this case as in the former the sum of the momenta is the same after impact as before it; but the bodies after impact do not move on together.

Prop. 70.—If an elastic body strike against a firm plane, the angle of reflection will be equal to the angle of incidence, p. 114.

PART II.

THE FUNDAMENTAL TRUTHS USED TO EXPLAIN THE PECULIARITIES OF STATE AND MOTION WHICH DEPEND ON THE SOLID FORM OF BODIES: A DEPARTMENT COMMONLY CALLED MECHANICS.

ANALYSIS OF THE CHAPTER.*

A force which moves part of a solid body, must affect the whole or break off the part.

If the force be directed towards a central point in the mass, it will affect the whole equally, whether simply to support the mass, or to move it, or to stop it when in motion. The point, according to circumstances, is called the CENTRE OF GRAVITY, OF INERTIA, *or* OF ACTION.

In solid bodies moving about an axis, as exemplified in a wheel or weighing beam, the various parts are describing circles or moving through spaces, which are greater in proportion to their respective distances from the centre of motion. Hence forces differing from each other as to speed, may still, through a solid medium, be brought exactly to co-operate or to oppose each other; and a slow force will counterbalance or be equivalent to a quicker one, provided that it be more intense in proportion as it is slower. The SIMPLE MACHINES *called* LEVER, WHEEL AND AXLE, PULLY, INCLINED PLANE, WEDGE, SCREW, *&c. are so many arrangements of solid parts, by which forces of different velocities and intensities may be thus connected or opposed, or conveniently substituted for each other.*

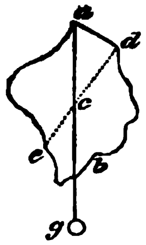
By solid connecting parts also the direction of any existing motion or force may be changed, as when the straight motion of running water is converted into the rotatory motion of a water wheel, &c. Hence arises an endless variety of COMPLEX MACHINES.

In all machines it is important to diminish the resistance among moving parts which arises from FRICTION, *and in solid structures generally, the forms and positions of parts must be adjusted to the* STRENGTH OF THE MATERIALS, *and to the strains which the parts have to bear.*

"*Solid*" is the term applied to a mass in which the mutual attraction of the atoms is so strong, that the mass may be moved

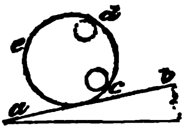
---

* The reader should here reperuse the general table or synopsis at page 43

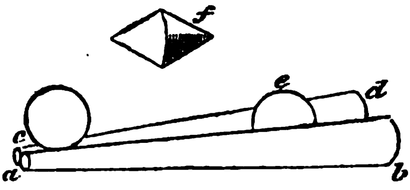


Thus if an irregular piece of plank or of pasteboard, represented here by the figure *a e b d*, be suspended from any point, as *a*, and the cord of a plummet *a g* be attached at the same point, the centre of gravity of the board must be somewhere in the direction of the plummet, and a chalk line left on the board where the cord touched it, must pass over the centre of gravity. If the board be then suspended by another point, as *d*, and another chalk line *d e* be made in the same manner, the place *c*, where the two lines cross or cut each other, will indicate the centre of gravity; and the board, when supported by a cord attached there, will hang evenly balanced.

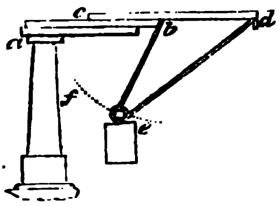
The following cases farther illustrate the truth, that the centre of gravity always seeks the lowest place. They seem at first to be exceptions to the law; but when more fully considered, are interesting proofs of it.



A wooden cylinder or roller *e d c*, placed on a slope or inclined plane *a b*, will naturally descend, because its centre of gravity is thereby approaching the earth; but if there be a heavy mass of lead *c* introduced at one side, which must rise before the roller can descend, the rise being contrary to gravity, the motion will be arrested. Indeed, if the roller were placed on the plane with the lead in the position *d*, this would fall down to the position *c*, and so would move the roller towards *b*, exhibiting the singular phenomenon of a body rolling up hill by the action of its weight.



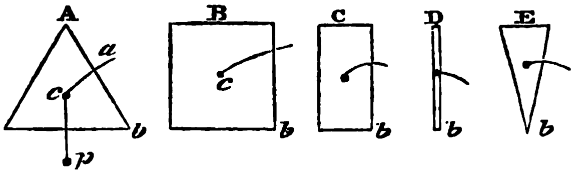
If a billiard ball be placed upon the small ends of two billiard sticks or cues *a b* and *c d*, laid on a table with their points *c* and *a* in contact, but with the larger ends *b* and *d* so far apart that the ball may lie, touching the table, between them, the ball will roll along between the cues, from its high situation near their points, to its lower situation near *b*. To a careless observer, it would then have the appearance of rolling upwards, because the cues are thicker towards the ends *d* and *b*; but it would really be descending in obedience to gravity. If a double cone, as represented at *f*, were substituted for the ball, it also would roll from *c* to *e*, and with still more of the fallacious appearance of rolling upwards, because its ends would always be resting on the upper and rising surfaces of the cues.



The board or stick *c d* resting on the edge of the table *a b* would naturally fall if left to itself, because more than half of it is beyond the edge of the table; but a weight *e* attached to it at *b* by the cord *e b*, instead of pulling it down faster, shall fix or steady it, provided the weight be pushed inwards a little by a rod *d e* resting against the weight and against a niche in the stick at *d*. It is evident that the stick *c d*, in falling, must turn round the edge of the table at *b*; but in so doing, after the arrangement now made, it must lift the weight *e* along the path *e f*—which rise, as the weight is heavier than the stick, gravity forbids, and therefore the stick and weight will both remain supported by the table. An umbrella or walking cane, hanging on the edge of a table by a crooked handle, is an instance of the same kind.

By attending to the centre of gravity of the bodies around us on earth, we are enabled to explain why, from the influence of gravity, some of them are stable or firmly fixed, others tottering, others falling.

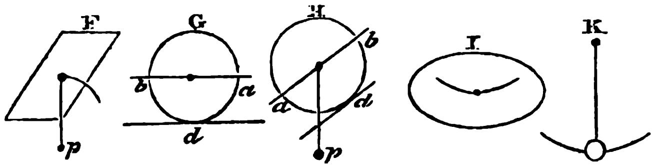
If we find that a body, from its form or position, cannot be overturned without its centre of gravity being lifted, knowing now that the whole mass must then be lifted in the same degree, we see why a weak cause cannot effect it. The rise of the centre of gravity, or body, in any case of falling over, will be proportioned to the breadth of the sustaining base of the body, compared with the height of its centre of gravity above that base. This is shown in the annexed figures, in which the two particulars of *base* and *height* are combined in a series of proportions. In all the figures, *c* or a dot marks the place of the centre of grav-ity, and the curved line beginning from the centre marks its path when the body is overturned. This curved line is a portion of a circle which has the edge or extremity of the base *b*, as a centre, because the body in turning must rest upon such extremity or corner as the centre of its motion. The farther inwards, therefore, from this extremity that the centre of gravity is, as marked by where a plumb line *p*, hanging from it, crosses the base, the farther of course is the centre of gravity from the top of the circle which it has to describe in moving, and the steeper, consequently, will be its commencing path : and here, as in the case of rolling bodies up slopes, the steeper the ascent, the greater will be the force necessary to give motion.—The line of a plummet hanging from a centre of gravity is called the *line of direction* of the centre, or that in which it tends naturally to descend to the earth.



In fig. A, which has broad base and little height of the centre of gravity, we see that this must rise almost perpendicularly before it can fall over, and the resistance to overturning is therefore nearly equal to the whole weight of the body. Hence the firmness of a pyramid.

In figures B, C, and D, progressively, the commencing path of the centre is less and less steep, and the bodies are so much the less stable. B may represent an ordinary house, C a tall narrow house, and D a lofty chimney.

Fig. E shows a tottering position, for the centre of gravity being directly over the base, which is a mere point, the least inclination places it on a descending slope, and the body must fall.



In F the position is tottering on one side, and stable on the other. This explains how the least inclination of a standing body virtually narrows its sustaining base.

In G, which represents a ball upon a level plane, the whole mass is supported on a single point as in E, yet the body has no tendency to move, because in any other possible position the centre would still be as far from the sustaining plane. In moving, the centre will describe the straight level line *a b*.

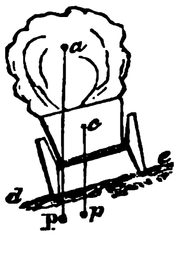
In H the ball is on an inclined plane, and rolls down, the centre of gravity describing the oblique line *b a*.

In I, which is an oval body on a level plane, when the body is moved, the centre of gravity describes the curve seen in the figure, like that of a pendulum. Hence an oval body on a level, rocks or vibrates like a pendulum.

K is a true pendulum whose centre of gravity describes the curve here shown; as explained in the first chapter, at page 105.

The importance of the subject of the centre of gravity will be farther judged of by the facts which are now to be reviewed.

A cart loaded with metal or stone may go safely along a road of which one side is higher than the other, as is here shown; but were the same cart loaded with wool or hay it would be overturned because, although the sustaining base be the same in the two cases, the *line of direction* falls much within it from the low centre of gravity of the metal at *c*, but falls very near the wheel at P, or altogether on the outside, from the high centre of the wool, at *a*, and in the latter case the centre has a falling path.



This explains why lofty stage coaches or vans are so dangerous particularly when heavy luggage is placed upon the top, and why lofty gigs and curricles are causes of so many fatal accidents. As regards any of these, a slight defect of smoothness or of level in the road, or even a slight lateral bend in a case of quick driving, suffices to produce the catastrophe. The safety coaches of late times are made with the wheels far apart to give a broad base, and with the luggage-receptacles and seats for the outside passengers placed low down before and behind the body of the carriage, instead of on the top as formerly.

The feet of tripods are generally expanded below to give a broad base. The same is true of our common chairs; but a thoughtless child often leans so far over the back of a chair, that he causes the line of the general centre of gravity to fall beyond the base, and the chair with its load is overturned. The small lofty chairs made to raise children to the parents' elbow at the dinner table, are very dangerous if the feet are not made to spread much. Pillar-and-claw tables, candlesticks, table-lamps, and many other articles of household furniture, have stability given in the same manner.

The least inclination of a standing body virtually narrows the supporting base.

This truth is explained by *fig. F.* It shows the necessity of building the thin walls and tall chimneys of modern houses perfectly upright. And hence the extreme importance and utility of that simple instrument the *plummet* or *plumb-line,* which when applied to a body, is a visible indication of the line of its centre of gravity. The mason and many other workmen cannot proceed a step without their guiding plummet.

The brick walls of modern houses are so thin, that, to have standing strength, they require to rest against each other; and hence they occasionally exhibit the kind of stability which belongs to a child's house built of cards. As contrasted with the masses of masonry which remain to us from antiquity, resting on firm-spreading basements, they are examples of what is truly ephemeral, in comparison with that which has partaken of the permanency of nature's own works, and has covered regions with mighty ruins. What magnificent illustrations of strength, and durability arising from proportion, are those ancient pyramids and temples, which still give such interest to the banks of the Nile, and to the valleys and plains of Asia!

There are many remarkable structures on earth which lean or incline a little: but so long as the line of their centre of gravity remains within the base, and the parts of the mass have tenacity among themselves sufficient to hold together, the structure will stand. The famous tower of Pisa was built intentionally inclining, to frighten and surprise: with a height of one hundred and thirty feet, it overhangs its base sixteen feet, and assumes nearly the air of Fig. F, in page 147.

The tall monument near London Bridge inclines so much, that in high winds from a particular quarter, timid minds begin to doubt of its stability.

And many of the most lofty and beautiful of our cathedral spires or towers, as that of Salisbury, &c., have lost something of their perpendicularity.

An oval body on a flat level surface, as already explained by fig. I, page 147, oscillates somewhat like a pendulum, because when disturbed from its middle position, its centre of gravity has risen and seeks to return. The same is true of the half of any solid globe: and such will always come to rest with its plane face turned directly upwards.

The rocking horse of children and the common cradle are exemplications of the same phenomenon.

But perhaps the most curious instances are those rocks called Loggan or Laggan stones, of which there are several among the picturesque barriers of the British coast. An immense mass, loosened in some convulsion of nature, is found with a slightly rounded base resting on a flat surface of rock below; and is so nearly balanced, that the force of one individual suffices to move it. Some of these have been objects of much superstitious veneration to their neighbourhood.

There is an amusing Chinese toy, made in obedience to the same principle, It has the appearance of a little fat laughing man, sitting with his feet concealed under him; but where the feet should be, the figure has a rounded smooth surface, with heavy lead ballast in it, placed so low, as always, when allowed, to raise the body to the erect or sitting attitude. A child pushes the little fellow down again and again, and would persuade him to repose, but is surprised to see him always up the moment after, shaking about and as lively as ever.

The vibratory motion of a pendulum, as dependent upon the centre of gravity having been moved from its lowest place which it again constantly seeks, was so fully considered in the last chapter, that it need not be again dwelt upon here. The following are other phenomena of the same class.

The vibrations of a common swing.

The rocking of a balloon when it first ascends.

The spontaneous shutting of those gates or doors which are suspended on the hinges so as to have somewhat of a forward or downward inclination, when in the shut position. Such a gate always returns of itself to the shut position, from either side, just as a pendulum returns to the lowest part of its arc.

The rocking or rolling of a ship, in particular states of the wind and sea. When the centre of gravity of a ship is too low, owing to all the heavy load being placed near the keel, this pendulum-motion, in rough weather becomes excessive and dangerous.

The actions and postures of animals, and particularly of man, illustrate beautifully the observations made above, with respect to the centre of gravity.

A body, we have seen, is tottering in proportion as it has great altitude and narrow base—but it is the noble prerogative of man to be able to support his towering figure with great firmness, on a very narrow base, and under constant change of attitude. This faculty is acquired slowly because of the difficulty. A child does well who walks at the end of ten or twelve months; while the young of quadrupeds, which have a broad supporting base, are able to stand and even to move about almost immediately.

The supporting base of a man consists of the feet and the space between them. The advantage of turning out the toes is, that without taking much from the length of the base, it adds a good deal to the breadth.

If there be considerable art in walking on two perfect feet, there must be still more in walking on two slender wooden legs with rounded extremities:—which we often see done, nevertheless, by mutilated soldiers and sailors.

All the ladies of the empire of China have to acquire nearly the same talent as these victims of war; for barbarous custom has crippled them, by confining their feet for life, in the shoes which fitted them in infancy.

But surpassing in difficulty any of these instances is the practice of walking on stilts, which is general among the inhabitants of the sandy plains called *Les Landes*, in the south-west of France. These plains afford tolerable pasturage for sheep; but during one portion of the year they are half covered with water, and during the remainder they are still very unfit walking-ground, by reason of their deep loose sand and thick furze. The natives combat the inconveniences of all the seasons by doubling the length of their natural legs, through the addition to them of the stilts mentioned, which they call *des échasses.* These are wooden poles, put on and off as regularly as the other parts of their dress. The people, when raised upon them, appear to strangers a new and extraordinary race of long-legged beings, marching readily over the loose sand, or through the water, with steps of eight or ten feet in length, and with speed equalling that of a trotting horse; their moderate journeys being of thirty or forty miles in a day. The shepherds, while watching their flocks, post themselves in convenient stations, with a long staff to support them behind, and having a rough sheep-skin cloak and cap to cover them above, like a thatched roof, they appear like little watch-towers, or singular lofty tripods, scattered over the face of the country.

Still beyond the art of walking on stilts is that which some persons attain of walking and dancing on a single rope or wire; or even of keeping the centre of gravity above the base, while standing on the moveable support of a galloping horse. The rope-dancer usually carries a long pole in his hand, to balance him; it is loaded at each end, and when he inclines, he throws it a little towards the side required, that the re-action may restore his body to perpendicularity.

Much art of the same sort is shown in the attitudes and evolutions of the skaiter; in the amusements of supporting a stick upright on the end of the finger; and in many other feats of a like kind.

Attitudes generally depend on the necessity of keeping the centre of gravity of the body over the base under variety of circumstance. The following are examples:—the straight or upright port of a man who carries a load on his head;—the leaning forward of one who carries it on his back;—the hanging backwards of one who bears it between his arms;—the leaning to one side of him who is carrying a weight on the other side;—the habitual carriage of very fat people, whose head and shoulders are thrown back, giving a certain air of self-satisfaction,—an air which belongs also to the state of pregnancy, and even to that of the dropsical patient, although producing in it so sad an incongruity.

When a man walks or runs, he inclines forward, that the centre of gravity may overhang the base: and he must then be constantly advancing his feet to prevent his falling. He makes his body incline just enough to produce the velocity which he desires.

A man, in pulling horizontally at a load, is merely causing his body to overhang its base, so that its tendency to fall may become a force or power applicable to the work.

When a man rises from a chair, he is seen first bending the body forward, so as to bring the centre of gravity over the feet or base, and then he lifts the body up. If he lift too soon, that is, before the body be sufficiently advanced, he falls back again.

A man standing with his heels close to a perpendicular wall, cannot bend forward sufficiently to pick up any object that lies on the ground near him, without himself falling forward; because the wall prevents him from throwing part of his body backward, to counterbalance the head and arms that must project forward. A man little versed in such matters, agreed to give ten guineas for permission to try to possess himself of a purse of twenty, thus laid before him; he of course lost his money.

When a man walks at a moderate rate, his centre of gravity comes alternately over the right and over the left foot. This is the reason why the body advances in a waving line, and why persons walking arm in arm shake each other, unless they make the movements of their feet to correspond, as soldiers do in marching.

Sea sickness is a subject closely related to the present. Man requiring, as now explained, so strictly to maintain his perpendicularity, that is, to keep the centre of gravity always over the support of his body, ascertains the required position in various ways, but chiefly by the perpendicularity or known position of things about him. Vertigo, and sickness, are the consequences of depriving him of his standards of comparison, or of disturbing them.

Hence on shipboard, where the lines of the masts, windows, furniture, &c. are constantly changing, sickness, vertigo, and other affections of the same class, are common to persons unaccustomed to ships. Many experience similar effects in carriages, and in swings; or on looking from a lofty precipice, where known objects being distant, and viewed under a new aspect, are not so readily recognized; also in walking on a wall or roof; in looking directly up to a roof, or to the stars in the zenith, because then all standards disappear: on entering a round room, where there are no perpendicular lines of light and shade, as when the walls and roof are covered with a paper which has no regular arrangement of spot: on turning round, as in waltzing, or if placed on a wheel; because the eye is not then allowed to rest long enough on any standard, &c.

All people in the dark, and therefore blind people always, use standards belonging to the sense of touch; and it is because, on board of ship, the standards both of sight and of touch are lost, that the effect is so very remarkable.

But sea sickness also partly depends on the irregular pressure of the bowels among themselves and against the containing parts, when their inertia or downward pressure varies with the rising and falling of the ship.

From the nature of sea sickness, as discovered in these facts, it is seen why persons unaccustomed to the motion of a ship, often find relief by keeping their eyes directed to the fixed shore, where it is visible; or by lying down on their backs and shutting their eyes; or by taking such a dose of exhilarating drink as shall diminish their sensibility to all objects of external sense.

No condition or form of matter escaping from the great laws of nature; we find the attitudes and general condition of vegetable as well as of animal bodies, characterized by the necessity of having the centre of gravity supported over the base.

With what admiration do we contemplate the pine and other trees in the forests of nature, springing up to heaven as perpendicular as if the plummet had been at work to direct them; and on the brows of precipitous hills as well as in the level plains. On a smaller scale, we see the grasses and corn-stalks of our cultivated fields, illustrating the same truth. And whenever, in tree or shrub, accident or peculiar nature causes a deviation from the laws of perpendicularity, additional strength and support are provided.

Beauty of form or position is often felt to exist in bodies, merely because they possess the shape and support required, that the centre of gravity may be stable.

In architecture, how displeasing is a wall or pillar that is not quite upright; or a column with too small a base; or a very tall narrow house; or a long slender chimney. On the other hand, how beautiful in a lofty edifice is the suitable succession of columns, from the massive Doric of the basement, which support the whole superstructure, to the light Corinthian or of kindred forms which are seen above. The Chinese pagoda is a fine example of the union of the requisites for stability, *viz.* perpendicularity and expanding base, with the other qualities of perfect symmetry, graceful proportion, and fanciful ornament.

When seen crowning a rising ground in a wooded island, or springing up from the centre of a rich garden, it forms, perhaps, one of the most beautiful objects which fancy has designed.

Beauty of attitude and *grace of carriage* in the human individual, are in great part referable to this principle.

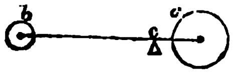
The postures of opera dancers might pass as intentional illustrations of the number of ways in which the centre of gravity may be kept above a narrow base, by counteracting one disturbing motion or extension of a limb by some opposite and corresponding motion. The common statue of the god Mercury on tiptoe is a permanent familiar illustration of a beautifully balanced attitude.

Grace of carriage includes not only a perfect freedom of motion, but also a firmness of step, or steady bearing of the centre of gravity over the base. It is usually possessed by those who live in the country, and according to nature, as it is called, taking much and varied exercise. What a contrast is there between the gait of the active mountaineer, rejoicing in the consciousness of perfect nature; and that of the mechanic or shopkeeper, whose confinement to the cell of his trade, soon produces in his body a shape and air that correspond to it:—and in the softer sex what a contrast is there, between that fair one who recalls to us the fabled Diana of old, and that other, who having scarcely trodden but on smooth pavements or carpets, under any new circumstances, carries her person as if it were a load altogether new and foreign to her.

The *centre of gravity* is also the *centre of inertia:*

If a person lifts a uniform rod by its middle, he overcomes the inertia of both ends equally, and they rise evenly together. If he lifts by a part nearer to one end, the shorter and lighter portion will rise the first, because the centre of inertia is in the other, and there will be a turning motion of the rod round the finger as a centre.

The *centre of gravity*, or *inertia*, however, is not neces-



sarily in the centre of he matter or mass;—for if a weight of three pounds, *a*, were affixed to one end of a rod, and a weight of only one pound, *b*, to the other, they would still be balanced, if supported or lifted by a point of the rod, *c*, three times nearer to the centre of the large weight, than to that of the small one,—and in this case, the centre of gravity would have three times as much matter on one side of it as on the other. This fact is explained under the lever, in the next chapter. For the sake of simplicity, in describing such experiments, the weight of the connecting rod itself is neglected.

The *centre of gravity* or *inertia* is also the *centre of centrifugal force*:—for if the balls *a* and *b* of the above figure were made to spin round a common centre, as by making the connecting rod rest and turn upon a pivot at *c*; unless the point *c* were the centre of inertia of the two; the pivot would always be pulled towards that end of the rod at which there were the greatest centrifugal force. It is on this account that for a millstone, or great fly-wheel, or the balance-wheel of a watch, the axis must pass through the centre of inertia, to prevent its being more worn on one side than on the other.

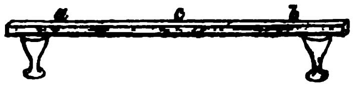
When we say, in astronomy, that the earth revolves round the sun, or the moon round the earth, we do not speak with absolute correctness; for in all such cases, both bodies are revolving round the common centre of inertia of the two. In the case of the sun and earth, as the former is almost a million times larger than the latter, the centre of inertia, being just so much nearer to its centre, is really within its body, although not in the exact centre.

The *centre of inertia* in a body is generally also the *centre* of *action* or *percussion*; because, if the centre of a body moving evenly come against an obstacle, the whole momentum of the body acts and is destroyed; while, if any other part than the centre hit, the body loses only a part of its momentum, and turns round the obstacle as a centre of motion, passing it on the side towards which the centre of inertia happened to be.

In a bar of iron, when used as a hammer, and in a pendulum, because the velocity of the different parts is different, and near the far extremity is greatest, the centre of all the motion and inertia is nearer to the fast moving end than to the other. Its exact place, in many cases, is easily ascertained by calculation. In a uniform rod, moving as a pendulum, it is at the distance of one-third from the lower end. In the pendulum it is called the *centre of oscillation.*

If a man use a bar or rod of iron as a hammer, he must take care to make it strike the object by its centre of action, or his own hand will receive a part of the shock. A very heavy mass thus used might do injury.—In a common hammer, as the chief part of the matter is at the end, the centre of percussion is there too, and no precaution of the kind mentioned above is necessary.

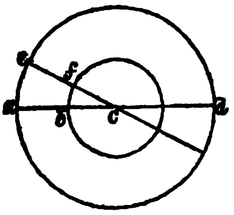
If a rod or small log of wood be suspended horizontally by a string tied to its middle, and if a forward blow be given across one end of it, the other end will be found, in the first instant, to have moved a little backward, as if the rod had been fixed upon an axis. The inertia of the general mass, by resisting the motion, becomes in effect a fixed axis. This truth is amusingly illustrated by laying the ends of a long stick on two wine-glasses, and then breaking the stick by a smart downward blow of a poker on its centre. Instead of breaking the glasses also by such a blow, as might be expected, the ends of the stick rise at the instant of the stroke, to turn round certain *centres of resistance,* as at *a* and *b,* in the fragments, and they then fall harmless on the table.



In this *section* we have seen what admirable simplicity is given to many of our reasonings and operations, by considering bodies in reference only to their *centre of inertia,* under one or other of its various names.

"*In a solid body moving about an axis, like a wheel or weighing-beam, the different parts have different velocities according to their respective distances from the axis or centre.*"

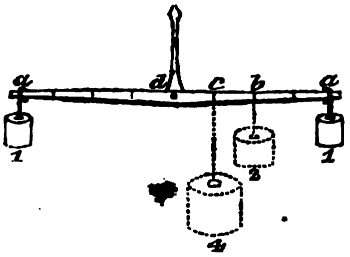
The truth of this proposition is perceived at once on comparing the moving rim of a wheel, or ends of a weighing beam with the parts nearer the centres. Suppose *a d* to be a line drawn upon a wheel or to represent a weighing-beam the centre in either case being at *c;* then the outer circular line *a c,* which the point at *a* describes when moving, is longer than the inner line, *b f,* which the point at *b* describes, in the same proportion as *a* is farther from the centre than *b*. This admits of easy mathematical demonstration, but may be satisfactorily ascertained by simple measurement of a figure drawn on paper. It is indeed merely an instance of the truth, that the proportion existing between any parts or lines in one circle, holds between the corresponding parts and lines in all other circles.



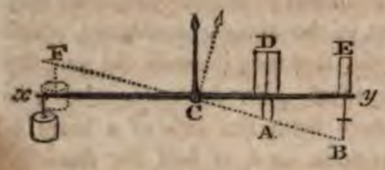
> " *Thus forces with different speed may still be placed in continued connexion or opposition; and they will balance or be equivalent, if the one be as much more intense than the other as it is slower.*" (*Read the analysis.*)

These are the two important truths upon which the whole of mechanics may be said to hinge. They give to man the *simple machines* or *mechanical powers,* as they have been called,—the lever, wedge, pulley, &c. which enable him to adapt any species and speed of power which he can command, to almost any work which he has to accomplish;—they may be said to have subjected external nature to his control. His works are of a thousand kinds, from the displacing of a rock, or the erection of an obelisk, to the spinning of a cotton thread, while the natural powers or forces at his command are chiefly wind, waterfalls, fire, and animal action—and of which in any particular case he may have only one kind at his service;—still, being able to connect together his power and resistance by solid media, of which different parts move with different velocities, he can employ any one for a purpose of almost any magnitude or kind.

There is, however, a false and most pernicious prejudice very generally existing with respect to the *simple machines,* which we must begin by removing, *viz.* that they increase the quantity of power or force applied to them. For instance, when one pound, as *a,* at a certain distance from the axis of a beam or lever, is seen balancing two pounds, as *b,* at half the distance, or four pounds, as *c,* at a quarter of the distance; many persons believe that the lever itself gives or begets a force equal to the difference of the weights in the different situations. But we shall now show, that levers and all the other *mechanical powers,* as they have been called, merely enable us to make up, by working longer, for what our strength would be unequal to if applied directly in other words to concentrate or divide any kind or quantity of force which we possess, so as to suit it to our various purposes, only as mill-ponds, and branching channels enable us to accumulate or divide the force of a stream of water ;—but they no more increase the *quantity of power* than the mill-pond increases the quantity of water. When a slender force then is caused, through a machine, to produce some effect which seems proportioned to an intense force, it will always be found that it has acted longer, or through more space than the other, in proportion as it is more slender: just as a small stream of water acting for ten minutes, may produce the same effect as a greater gush in one minute. Twenty feet of the action of a small horse near the circumference of a great wheel, will be equivalent to ten feet of the action of a heavy ox nearer the centre. By intervening machinery, one horse in drawing through six-hundred feet, or a hundred horses in drawing through six feet, may be made to do the same work as the piston of a great steam-engine, in rising once from the bottom to the top of its cylinder, &c.



To illustrate this subject farther: suppose a weighing-beam

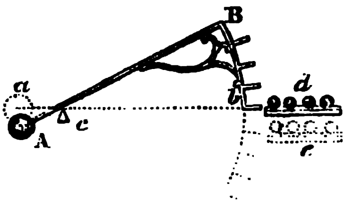


x y, with a weight of one pound hanging at the end x: if a spring issuing from the fixed box at E, with uniform force of one pound, be made to push at the other end of the beam y, it will just balance the weight; and if it be in the slightest degree stronger than the weight; it will push the end of the beam y down to B, and will raise the weight to F. If, instead of the single spring of one pound at the end of the beam B, two such springs be applied at half way to the centre, or at A,—where there is, consequently, just half as much extent of motion, or room to act in,—exactly the same effect will follow. Now because one spring at the end of the beam E, is seen here doing the same work as two such springs, or a single spring of double strength, at the middle D, it might appear at first that there were a saving of power by using the single spring and longer lever; but let it be remembered, that the two middle springs have each issued from their box only one inch, while the single spring at the end has issued two inches; and in both cases, therefore exactly two inches of pound-spring have been used.

In the last experiment, pound weights or little buckets of water might be used instead of the springs, and with exactly the same result—one pound or pint at the end of the arm producing the same effect as two pounds or pints at the middle of it; but it would be observed that the single quantity fell two inches, while the double quantity at half distance fell only one inch; and to replace them after they had done their work, there would be exactly the same labour, whether a person had to lift the single quantity first one inch, and then another, or whether to lift half of the double equipoise an inch, and then the other half as much.—Each atom of matter may be considered as held to the earth by its thread of attraction, and if one atom rise or fall ten inches, just as much of the supposed thread of attraction will be drawn out or returned as if ten atoms rise or fall one inch. And, where a weight of one pound is made to do any work instead of a weight of two pounds, there is no more saving than in giving away two yards of single rope instead of one yard of double rope; and in like manner for all other differences of intensity.

If a man were to exert a force of one hundred pounds at A, in the above figure, to lift the weight, a boy at B, with force of fifty pounds, might do the same thing; but the man would only have worked or pressed down through one foot, while the boy would have worked through two; therefore, although the boy with the assistance of the lever, seemed to become as strong as the man, the case would merely be, again, that of the one-pound spring unbending two inches, to produce an effect equal to that of the two-pound spring unbending one inch. The boy uses two feet of his smaller force, where the man uses one foot of his greater force; and if the work had to be continued, the boy would have completely exhausted himself when the man was yet fresh.—Is it wonderful then, that the boy should be able to accomplish for a little time what the man does, with a machine, of which the construction enables him to use twice as much of his smaller power, to accomplish the purpose, as the man can use in the same time of his larger power?

Another case of the lever, exhibited in the adjoining diagram, serves well to explain the nature of *mechanical powers* in general. Suppose A to be a weight of four pounds at the end of the rod or lever A B, turning on C as an axis or fulcrum, and having the arm C B four times as long as the arm C A: one pound at the end B, would balance the four pounds at the end A, and the slightest additional weight would cause it to preponderate. Now let us suppose the arc B *b* fixed to the long arm of the lever, and having four projections or shelves from it, on which balls of one pound might rest: if one of the four balls from the plane *d* were to roll upon the first shelf, with one grain more, it would lift A, and



would itself descend to the plane *e*, one inch below; *then a second ball of one pound would occupy the second shelf, and would descend in the same way, and then a third, and then the fourth; and when the whole had fallen from *d* to *e*, they would just have lifted the four pound weight, at the other end of the lever, one inch. Then, although one pound were seen here lifting four pounds, it would only have lifted it one-fourth part as far as it fell itself, and the sum of the phenomenon when ended would be, that four pounds, by falling one inch at the long end of the lever, would have lifted four pounds one inch at the short end. No *mechanical power* or *machine* generates force more than the lever in this case.

It appears, then, from all this, that as the *quantity of motion* in a body is measured by its velocity, and the number of atoms in it conjointly, so the *quantity of force* exerted in any case, is measured by the *intensity* of the force conjointly with the *space* through which it moves; and therefore a clear mode of speaking of forces in comparing them is to state the *lengths* and the *intensities*—for instance, to speak of ten feet of one-pound force, or of one foot of ten-pound force.

A horse pulling with a force of fifty pounds goes generally at the rate of six miles an hour:—the steam-engine piston generally moves at the rate of two hundred feet per minute, and has a pressure of steam of about twenty pounds to each square inch of its surface:—a certain mill-stream may have a force of one hundred pounds, and a velocity of a hundred and fifty feet per minute. Now it is easy, by simple arithmetic, and the rule of *length* and *intensity* above explained, to compare all these and other forces as applicable to any work.—We must warn the reader, however, that there are many important considerations connected with the practical employment of forces, according to their respective nature, and that of the resistance to be overcome, which cannot be entered upon in this elementary work. In very many cases there is a great waste or unavoidable loss of force, because the resistance in yielding runs away or escapes from the force, as when a ship runs away from the wind which is driving her, or the floats of a quick moving water-wheel from the stream which turns it. Horses drawing boats or carriages at the rate of five miles an hour, may exert great force, but with a speed beyond twelve miles, nearly their whole effort is required to move their own bodies. As a general rule, although *equal quantities* of force balance each other when applied to parts of a lever or wheel altogether or nearly at rest, still when force is made to act near an axis or fulcrum, to produce considerable velocity in a more distant part, much of it is wasted in pressure against the fixed fulcrum.

---

* The ball must be supposed here to roll off.

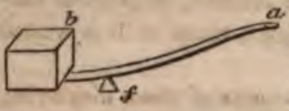
What an infinity of vain schemes—some of them displaying great ingenuity—for perpetual motions, and new mechanical engines of power, &c. would have been checked at once, had the great truth been generally understood, that no form or combination of machinery ever did or ever can increase, in the slightest degree the quantity of power applied. Ignorance of this is the hinge on which most of the dreams of mechanical projectors have turned. No year passes, even now, in which many patents are not taken out for such supposed discoveries; and the deluded individuals, after selling perhaps even their household goods to obtain the means of securing the supposed advantages, often sink in despair, when their attempts, instead of bringing riches and happiness to their families, end in disappointment and utter ruin. The frequency and eagerness and obstinacy with which even talented individuals, owing to their imperfect knowledge of this part of natural philosophy, have engaged in such undertakings, is a remarkable phenomenon in human nature. Examples of such schemes will be noticed in different parts of this work, where they may serve to illustrate points under consideration.

"*Lever, wheel and axle, &c.*" (*Read the analysis at page* 141.)

These are the simplest of the contrivances, which the circumstance of solidity in masses has enabled man to adopt, for the purpose of connecting or opposing forces and resistances of different intensities. We proceed to describe them, and to explain some of their useful applications.

"*Lever.*"

A beam or rod of any kind, resting at one part on a prop or axis which becomes its centre of motion, is a lever; and it has been so called, probably, because such a contrivance was first employed for lifting weights.



This figure represents a lever used to move a block of stone: *a* is the end to which the *power* or *force* is applied, *f* is the *prop* or *fulcrum*, and the mass *b* is the *weight* or *resistance*. According to the rule already given and explained at page 157, the power may be as much less intense than the resistance, as it is farther from the fulcrum, or moving through a greater space. A man at *a*, therefore, twice as far from the prop as is the centre of gravity of the stone *b*, will be able to lift a stone twice as heavy as himself; but he will only lift it one inch for every two inches that he descends: and it would require two men acting at half the distance, to do the same work.

There is no limit to the difference of intensity in forces, which may be placed in opposition to each other by the lever, except the length and strength of the material of which the levers must be formed. Archimedes said, "give me a lever long enough, and a prop strong enough, and with my own weight I will move the world." But he would have required to move with the velocity of a cannon ball for millions of years, to alter the position of the earth by a small part of an inch. As stated in a former part of the volume, this feat of Archimedes is, in mathematical truth, performed by every man who leaps from the ground, for he kicks the world away from him when he rises, and attracts it again when he falls back.

To calculate the effect of a lever in practice, we must always take into account the weight of the lever itself and its bending; but in speaking of the theory of the lever, we usually leave these for the time, out of the question, considering it as a rod without weight and without flexibility.

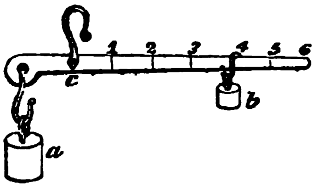
The rule for the lever, that opposing forces, to balance each other, must be more or less intense, exactly as they act nearer to or farther from the centre, holds in all cases, whether the forces be on different sides of the prop or both on the same side, and whether the force nearest to the prop have the office of power or of resistance; it holds also, whether the lever be straight or crooked.

The following are examples of levers with the prop between the forces.

The *handspike*; represented in page 164 as moving a block of stone. The same form when made of iron, and having its extremity formed into claws, is called a *crow-bar*. Both kinds are used by gunners, in working cannon during battle; they are also used generally for lifting and moving heavy masses through small spaces, as the materials of the mason, the ship-builder, the warehouseman, &c. A short crow-bar is the instrument of housebreakers for wrenching locks open, tearing off hinges, &c.

The common *claw-hammer*, for drawing nails, is another example. A boy who cannot exert a direct force of fifty pounds, may yet by means of this kind of hammer extract a nail to which half a ton might be suspended,—because his hand moves through perhaps eight inches, to make the nail rise one-quarter of an inch. The claw-hammer also proves, that it is of no consequence whether the lever be straight or crooked, provided it produces the required difference of velocity between power and resistance. The part of the hammer resting on the plank is the fulcrum.

Pincers or *forceps* are double levers, of which the hinge is the common prop or fulcrum. In drawing a nail with steel nippers, we have a good example of the advantages of using a tool: 1, the nail is seized by teeth of steel instead of by the soft fingers: 2, instead of the griping force of the extreme fingers only, there, is the force, of the whole hand conveyed



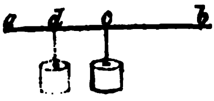
The *steelyard* is a lever with unequal arms. If we suppose the hook at the short end to be one inch from the centre of support *c*, a pound weight on the long arm will always balance as many pounds at the short arm as the pound is inches distant from the fulcrum. This supposes, however, that the steelyard when bare hangs horizontally, from having a greater mass of matter in the short arm to balance the long slender arm from which the shifting weight hangs. In the figure, one pound is seen balancing four pounds.

The Chinese, who are so remarkable for the simplicity to which they have reduced their common implements, weigh all small objects by a delicate steelyard. It is a wooden rod of about six inches in length, with a silk cord passing through it at a particular part, and knotted below to serve as a fulcrum, and with a sliding weight on the long arm, and a small scale attached to the short one.

The following are examples of levers with both forces on the same side of the prop, and with the more distant force as the power.

A common wheel-barrow;—in using which a man bears as much less than the whole weight of the load, as the centre of gravity of the load is nearer to the axle of the wheel than to him.

Two porters carrying a load between them on a pole, share it equally, if it be in the middle between them;—each porter becoming a fulcrum to the lever, as regards the other: but if it be nearer to one end, he to whom it is nearest bears proportionally more of its weight. A load at *c* is equally borne by a porter at *a* and by one at *b;* but a load at *d* gives three-quarters of its weight to the man at *a*, and only one-quarter to him at *b*.



Two horses drawing a plough, act by a cross-tree which has its middle hooked to the plough, and a horse attached to each end. The horses must thus pull equally to keep the tree directly across. When three horses are yoked, in heavy land, two of them may draw from one end of the cross-tree, but this must then be attached to the plough by a hook twice as far from one end of it as from the other.

The oar of a boat is a lever of this kind, although the fulcrum is the unstable water.

The common nut-crackers, also, by the lever-power of which a person can break a shell ten times as strong as he could with the bare fingers.

The consideration of this kind of lever explains, why a finger caught near the hinge of a shutting door is so much injured. The centre of action of the door moves through a space comparatively great, and acts with a great lever-advantage on a resistance placed near the fulcrum of the lever where there is little motion. Children pinching their fingers in this way, or in the hinge of the fire-tongs, where there is a similar action, wonder why the bite is so keen.

The phenomenon of the branch of a tree giving way, when overloaded with fruit in autumn, or with snow in winter, also exhibits the action of this kind of lever. The resistance is the cohesion of the upper side of the branch to the tree, and the fulcrum is the part below which is last broken.

The following are examples of the lever, where the two forces are on the same side of the pivot, and where the one nearest to the pivot acts as the power. In this kind, the power is more intense than the resistance.

The hand of a man who pushes open a gate while standing near the hinges, moves through much less space than the end of the gate, and hence must push with great force.

When a man uses the common fire-tongs, the ends move much farther than his fingers, and therefore with less strength;—no one fears a pinch with the ends of the fire-tongs.

The most beautiful and remarkable instances of this modification of lever are in the limbs of animals. The object in these was to give to the extremities great range and freedom of motion, without clumsiness of form; and it has been obtained most perfectly, by inserting the moving tendons or ropes near to the joints, which are the pivots or fulcra of the bone-levers.

In the human arm, the deltoid muscle, which forms the cushion of the shoulder, by contracting its fibres less than an inch, raises the elbow twenty inches; and of course, if it overcome a force of fifty pounds at the elbow, it must itself be acting with a force at least twenty times as intense, or of one thousand pounds.—What extraordinary strength of muscle, then, is displayed, by a man who lifts another at the end of his extended arm; yet this by some is done with ease, and even on both sides at once.

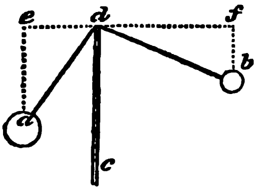
How powerful must be the wing-muscles of birds, which, by this kind of action, sustain themselves in the sky for many hours together. The great albatross, with wings extended fourteen feet or more, is seen in the stormy solitudes of the Southern Ocean, accompanying ships for whole days without ever resting on the waves.

A little contraction of the glutæi muscles of the hips gives to the human step a length of four feet.

While the erroneous opinion prevailed, that machines increased power, instead of, as they do, merely accommodating forces to purposes, this last kind of lever, where a great force acting through a short distance is made to gain great extent of motion and other benefits, was regretted by many as a most unprofitable contrivance, and was called the *losing lever*.

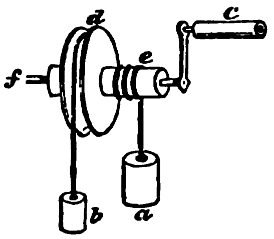
It is almost unnecessary to say, that the same rule of comparative velocities ascertains the relations required in power and resistance where a combination of levers is used, as where there is only one. If a lever which makes *one* balance *four*, be applied to work a second lever which does the same, *one* pound at the long arm of the first will balance *sixteen* pounds at the short arm of the second lever, and would balance *sixty-four* at the short arm of a third such, &c.

The general rule for the lever, that a force may be less intense the farther it is from the pivot, supposes always that the force acts at right angles, or directly across the lever; for if there be any obliquity, there is a corresponding diminution of effect, as explained under the head of *resolution of forces,* at page 101.

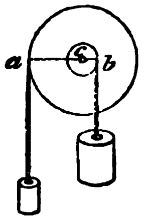


For instance, one pound at *b* on the end of the long arm of the bent lever *b d a,* because its weight does not act directly across *b d,* has influence only as if it were acting directly at the end of a shorter horizontal arm *f d;* and the two-pound weight at *a* acts only as if it were on a horizontal arm at *e;* now *e* being only half as far from the centre as *f,* two pounds at *a,* in the position of the lever here shown, would just balance the one pound at *b.* In every case, the exact influence of weights may be known by referring them to places directly above or below them, on a supposed horizontal lever *e f.* What is called a *bent lever balance,* is made on this principle. It has on one side a heavy weight at *a,* and on the other side a scale attached at *b;* and the weight of any thing put into the scale is known by the comparative distances, after equilibrium is produced, of *a* and *b* from the support *c d.* This distance is exhibited on the line *e f,* as described above.

" *The wheel and axle*"

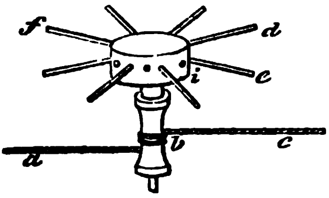


is the next of the *simple machines.* The letter *d* here marks a wheel, and *e* an axle affixed to it; and we see that in turning together, the wheel would take up or throw off as much more rope than the axle as the circumference or diameter of the wheel were greater than that of the axle. If the proportions were as four to one, one pound at *b,* hanging from the circumference of the wheel, would balance four pounds at *a,* hanging from the opposite side of the axle.



This figure represents the same object as the last, when viewed endways. It explains why the wheel with its axle has been called a perpetual lever; for the two weights hanging in opposition, on the wheel at *a*, and on the axle at *b*, are always as if they were connected by a horizontal lever *a c b*, turning on the centre *c* as its prop: and while the simple lever could only lift through a small space, it is evident that this construction will lift as long as there is rope to be wound up.

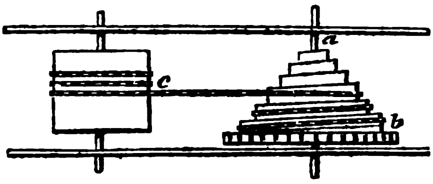
A common crane for raising weights, consists of an axle to wind up or receive the rope which carries the weight, and of a large wheel at the circumference of which the power is applied. The power may be animal effort on the outside of the wheel, or the weight of a man or beast walking in the inside, and moving it as a squirrel moves the cylinder of its cage.



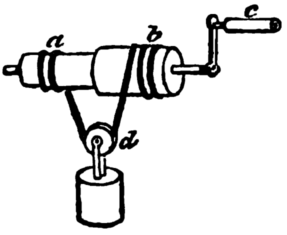
The *capstan* on board of ships, is merely a large upright axle or spindle *b*, which by turning pulls the cable or rope *a b c*. It is turned by the men pushing at the capstan-bars *d*, *e*, *f*, &c., which for the time are stuck into holes made for them in the broader part or drum, usually appearing above the deck, at the top of the spindle. These bars may be considered as the spokes of a large wheel, and the effect produced by a man working at one of them is in proportion to his distance from the centre. The capstan is chiefly used on board ships for lifting the anchor, and for doing any other very heavy work; but it is also applied to many purposes on shore.

The common *winch* (represented as attached to the wheel and axle in page 171, at the letter *c*,) with which a grindstone is turned, or a crane worked, or a watch wound up, is really in principal a wheel: for the hand of the worker describes a circle, and there is no difference in the result whether an entire wheel be turning with the hand or only a single spoke of a wheel.

That part of a common watch called the *fusee* is as beautiful an illustration of the principle of the wheel and axle now under consideration, as it is a useful and ingenious contrivance. The spring of a watch, immediately after winding up, being more bent, is acting more powerfully than afterwards when slacker, and if there were no means of equalizing its action, it would destroy the wished-for uniformity in the motion, of the time-pieces. The fusee is this means. It may be considered as a barrel or spindle, gradually diminishing from its large end *b*, to its small end *a*, with the surface cut into a spiral groove to receive the chain by pulling at which the spring in the box *c* moves the watch. Now then when the watch has been wound up, by a key applied on the axis of the fusee, the fusee is covered with the chain up to the small end *a*, and the newly bent and strong spring begins to pull by this small end or short lever; afterwards, exactly as the spring becomes relaxed and weaker, it is pulling at a larger and larger part of the fusee-barrel, and so keeps up an equal effect on the general movement.

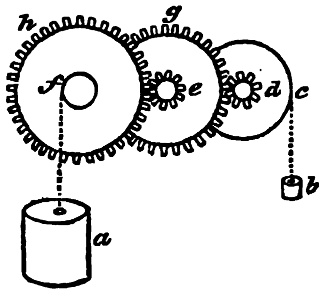


A large fusee in place of a common cylindrical axle, is often used with a winch, for drawing water by bucket and rope from very deep wells. When the bucket is near the bottom of the well, and the labourer has to overcome the weight of the long rope, in addition to that of the bucket and water, he does so more easily by beginning to wind the rope on a small axle, that is to say, on the small end of the fusee; and in proportion as the length of the rope diminishes, he is lifting by a larger axle.



By the double axle *a b*, very unequal intensities of force may be balanced. We see that in turning it, a rope unwinding from the small end *a*, is taken up by the large end *b*, turn for turn, and that the rope below must be shortened at each turn by the difference between the circumference of the ends, *a* and *b*. If the weight rise half-an-inch only, while the handle of the winch describes a circle of fifty inches; one pound force at the winch would balance one hundred pounds at *d*.

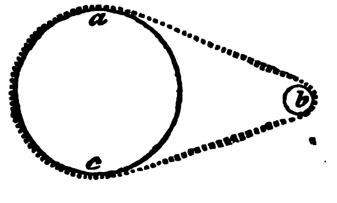
By means of a wheel which is very large, in proportion to its axle, forces of very different intensities may be balanced, but the machine becomes of inconvenient proportions. It is found preferable, therefore, when a great difference of velocity is required, to use a combination of wheels of moderate size. In the adjoining figure three wheels are seen thus connected. Teeth on the axle *d*, of the first wheel *c*, acting on six times the number of teeth in the circumference of the second wheel *g*, turn it only once for every six times that *c* turns; and in the same manner the second wheel, by turning six times, turns the third wheel *h* once; the first wheel, therefore, turns thirty-six times for one turn of the last; and as the diameter of the wheel *c*, to which the power is applied, is three times as great as that of the axle *f*, which has the resistance: three times thirty-six, or one hundred and eight, is the difference of velocity, and therefore of intensity, between weights or forces that will balance here. An axle with teeth upon it, as *d* or *e*, is called a pinion.



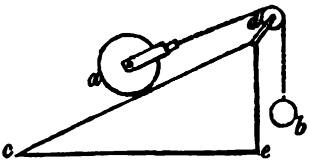
On the principle of combined wheels, *cranes* are made, by which one man can lift many tons. It is even possible to make an engine, by means of which a little windmill, of a few inches in diameter, should tear up the strongest oak by the roots; but of course it would require a very long time for its work.

The most familiar instances of wheel-work are in our clocks and watches. One turn of the axle on which the watch-key is fixed, is rendered equivalent, by the train of wheels, to about four hundred turns or beats of the balance-wheel; and thus the exertion during a few seconds, of the hand which winds up, gives motion for twenty-four or thirty hours. By increasing the number of wheels, time-pieces are made which go for a year: if the material would last, they might easily be made to go for a hundred or a thousand years.

Wheels may be connected by bands as well as by teeth. This is seen in the common spinning wheel, in turning lathes, grind-stones, &c. &c. A spinning wheel, as *a c*, of thirty inches in circumference, turns by its band a pirn or spindle of half an inch, *b*, sixty times for every turn of itself.



" *The inclined plane*"



is the third means, which we shall describe, of balancing forces of different intensities, by solid media. A force pushing a weight from *c* to *d*, only raises it through the perpendicular height *e d*, by acting along the whole length of the plane *c d;* and if the plane be twice as long as it is high, one pound at *b*, acting over the pulley *d*, would balance two pounds as at *a*, any where on the plane: and so of all other quantities and proportions.

A horse drawing on a road where there is a rise of one foot in twenty, is really lifting one twentieth of the load, as well as overcoming the friction and other resistance of the carriage. Hence the importance of making roads as level as possible; and hence the error of our forefathers, in often carrying their roads directly over hills, for the sake of straightness considered vertically, where, by going round the bases of the hills they would scarcely have had greater distance, and would have avoided all rising and falling. Hence, also, a road up a very steep hill must be made to wind or zig-zag all the way: for to reach a given height, the ease of the pull to the horses is greater exactly as the road is made longer. This rule of road-making is exhibited remarkably in various parts of the world, on hills with almost perpendicular face, where very safe and commodious roads have been made, leading to forts or residences near the summits. An intelligent driver, in ascending a steep hill by a broad road, winds from side to side all the way, to save his horses a little.

The railways of modern times offer a beautiful illustration of this subject. They are made either perfectly level, so that the drawing horse or steam-engine has only to overcome the friction of the carriage; or, where heavy loads are passing only in one direction, as from mines, they are made to slope a very little, so that the horse or other power has only to regulate the movement.

Hogsheads of merchandize, which twenty men could not lift directly, are often seen moved out of or into wagons, by one or two men, who have the assistance of inclined planes. In some canals, the loaded boats are drawn up by machinery on the inclined planes, instead of being raised in locks as is usual.

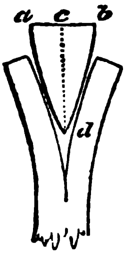
It is supposed that the ancients (the Egyptians particularly) must have used the inclined plane, to assist in elevating and placing those immense masses of stone, which still remain from their times, in their gigantic pieces of architecture.

Our common stairs are inclined planes in principle; but, being so steep, are cut into horizontal and perpendicular surfaces, that they may afford a firm footing.

A body falling freely, in obedience to gravity, descends about sixteen feet in the first second, as already explained at page 103. If made to roll down an inclined plane, it moves just as much slower than this (supposing no friction nor loss from the turning produced,) as the length of the plane is greater than the height. In a plane falling one foot in sixteen of its length, a body would roll down only one foot in the first second.

The descent of a pendulum in its arc is investigated mathematically by the laws of the inclined plane, which it exactly obeys. And the laws of the inclined plane itself are mathematically examined by the principle of the *resolution of forces*, explained at p. 100.

"*The wedge*"



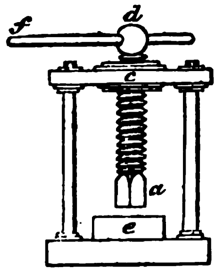
is merely an inclined plane force forward between resistances to separate or overcome them, instead of, as in the last case, being stationary, while the resistance is moved along its surface. The same rule as to mechanical advantage has been applied to both cases: the force acting on a wedge being considered as moving through a space equal to its *length c d,* and the resistance as yielding through a space equal to its breadth *a b.* But this rule is far from explaining the extraordinary power of a wedge. It appears, that during the tremor produced by the blow of the driving hammer, the wedge insinuates itself and advances much more quickly than the above rule anticipates.

The wedge is used for many purposes; as for splitting blocks of stone and wood; for squeezing strongly, as in the oil press for lifting great weights, as when a ship of war, in dock, is raised by wedges driven under the keel, &c.

An engineer in London, who had built a very lofty and heavy chimney for his steam engines and furnaces, found after a time that it was beginning to incline, owing to the dampness of the foundation. However, by driving wedges under one side of it, he succeeded in restoring it to perfect uprightness.

Nails, awls, needles, &c. are examples of the wedge; as are also all our cutting instruments, knives, razors, the axe, &c. These latter are often used somewhat in the manner of a saw—which is a series of small wedges,—by pulling them lengthwise at the same time that they are pressed directly forward against the object. It appears that the vibration of the particles produced by this drawing action enables the edge to insinuate itself more easily. The sharpest razor may be pressed directly against the hand with considerable force, and will not enter, but if then drawn along ever so little, it will dart into the flesh

"The Screw"



is another of the simple machines. It may be called a winding wedge, for it has the same relation to a straight wedge that a road winding up a hill or tower has to a straight road of the same length and acclivity.

A screw may be described as a spindle *a d*, with a thread wound spirally round it, turning or working in a nut *c*, which has a corresponding spiral furrow fitted to receive the thread. The nut is sometimes called the female screw. Every turn of the screw carries it forward in a fixed nut, or draws a moveable nut along upon it, by exactly the distance between two turns of its thread: this distance, therefore, is the space described by the resistance, while the force moves in the circumference of the circle described by the handle of the screw, as at *f* in the figure. The disparity between these lengths or spaces is often as a hundred or more to one; hence the prodigious effects which a screw enables a small force to produce.

Screws are much used in presses of all kinds: as in those for squeezing oil and juices from vegetable bodies, as linseed, rapeseed, almonds, apples, grapes, sugar-cane, &c. &c.;—they are used in the cotton-press, which reduces a great spongy bale, of which a few, comparatively, would fill a ship, to a compact package, heavy enough to sink in water;—in the common printing press, which has to force the paper strongly against the types;—a screw is the great agent in the coining machinery at our mints—and in letter-copying machines;—it is a screw which draws together the iron jaws of a smith's vice, &c. &c.

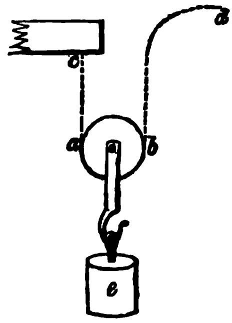
As a screw can easily be made with a hundred turns of its thread in the space of an inch, and at perfectly equal distances from each other, it enables the mathematical instrument-maker to mark divisions on his work, with a minuteness and accuracy quite extraordinary. If we suppose such a screw to be pulling forward a plate of metal, or the edge of a circle, over which a sharp-pointed steel marker is placed, which moves up and down perpendicularly, the marker, if let down once for every turn of the screw, will make just as many lines on the plate; but if made to mark at every hundreth or thousandth of a turn of the screw, which it will do with equal accuracy, it may draw a hundred thousand distinct lines in one inch.

The micrometers, by which the sizes of the heavenly bodies and of microscopic objects are ascertained, are worked by screws.

A *perpetual screw* is the name given where a screw acts on the teeth of a wheel, so as to give it continued motion.

The screw is an exceedingly useful contrivance, although producing so much friction as to consume a considerable part of the force used in working it.

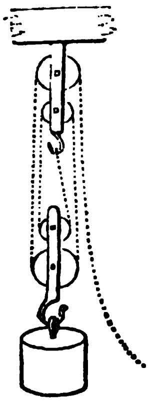
A common cork-screw is the thread of a screw without the spindle, and is used, not to connect opposing forces, but merely to enter and fix itself in the cork. There are complicated cork-screws now made, which draw the cork by the action of a second screw, or of a toothed rod or rack and pinion.



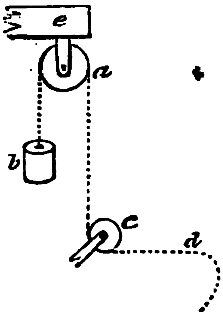
" *The pulley*" is another *simple machine*, by which forces of different intensities may be balanced. A simple pulley consists of a wheel as *a b*, which rests with its grooved circumference on the bend of a rope, *c a b d*, and to the axis of which the weight or resistance is attached, as at *e*.

In such a construction, it is evident that the weight (let it be supposed ten pounds) is equally supported by each end of the rope, and that a man holding up one end, only bears half of it, or five pounds; but to raise the weight one foot, he must draw up two feet of rope; therefore, with the pulley he lifts five pounds two feet, where he would have to lift ten pounds one foot without the pulley.

Many wheels may be combined together, and in many ways to form compound pulleys. Wherever there is but one rope run-



ning through the whole, as shown here, the relation of power and resistance is known by the number of folds of the rope which support the weight. Here there are four folds, and a power of one hundred pounds would balance a resistance of four hundred. As persons using pulleys, generally find it more convenient to stand upon the ground than to go up and apply their force directly to one of the supporting ropes, the last supporting rope is commonly made to pass over a wheel above, and to come down apart from the others, as seen here. This portion not being directly connected with the weight, adds convenience to the pulley, but is not to be counted with the others, in estimating the relation of the power and resistance.



In *fixed pulleys*, like those shown at *a* and *c*, there is no mechanical advantage, for the weight just moves as fast as the power; yet such pulleys are of great use in changing the direction of forces. A sailor, without moving from the deck of his ship, by means of such a pulley, may hoist the sail or the signal-flag to the top of the loftiest mast. And in the building of lofty edifices, where heavy loads of material are to be sent up every few minutes, a horse, trotting away with the end of the rope from *d*, in a level court-yard, causes the charged basket *b* to ascend to the summit of the building as effectually as if he had the power of climbing the perpendicular wall with it, at the same rate.

There is a case, however, in which a fixed pulley may seem a balancer of different intensities of force; *viz.* where one end of a rope is attached to a man's body, and the other is carried over a pulley above, and brought down again to his hands;—for safety this end also should be attached to his body. By using the hands then to pull with force equal to half his weight, he supports himself, and may easily raise himself to the pulley. A man, by a pulley thus employed, may let himself down into a deep well, or from the brow of a cliff, with assurance of being able easily to return, although no one be near to help him; and cases have often occurred where, by such means, a fellow-creature's life might have been saved, or other important objects attained. How easily, for instance, might persons either reach or escape from the elevated windows of a house on fire, by a pulley which might readily be found and carried where ladders could not be obtained!—Such a pulley furnishes a convenient means of taking a bath, without assistance, from a ship's stern windows, &c.

The chief use of the pulley is on ship-board. It is there called a block, although strictly speaking, the block is only the wooden mass which surrounds the wheel or wheels of the pulley. It aids so powerfully in overcoming the heavy strains of placing the anchor, hoisting the masts and sails, &c., that by means of it a smaller number of sailors are rendered equal to the duties of the ship. Pulleys are also used on shore, instead of cranes and capstans, for lifting weights, and overcoming other resistances.

Surgeons, in former days, when they trusted rather to force than to the address which better information gives, used pulleys much to help in the reduction of luxations,—but often hurtfully, from not understanding the force of the pulley. A man who should now ignorantly stretch his patient on the rack, would be well requited by similar treatment.*

The cranks of bell-wires, seen in the corners of our rooms, are bent levers nearly equivalent to fixed pulleys.

There is no reason, but old usage, why the appellation of mechanical power should be confined to the six contrivances now explained, for those of which the account is yet to follow equally deserve it; and, as will be seen under hydrostatics in the lower; so that the end *c* darts outwards much farther than the ends *a* and *b* approximate.

---

* Pulleys are still used, by surgeons, in the reduction of luxations, and when properly applied, with great advantage. AM. ED.

Different intensities of force are balanced, although not simultaneously, by the following means, which therefore, according to the old idea, have some claim to the name of *mechanic powers*.

A man may have an object to effect, which a forcible downward push would accomplish: but his body being too weak to give that push directly, he may employ a certain time in carrying a weight up to such an elevation above his work, that when let fall its momentum may do what is required. Here the continued effort of the man in lifting the weight to a height of perhaps thirty feet may be just sufficient to produce a blow which will cause a stake or pile to sink into the earth one inch; and the contrivance has therefore balanced forces, which are to each other in intensity as thirty feet to an inch.

So also hammers, clubs, battering rams, slings, &c. are machines which enable a continued moderate effort to overcome a momentary great resistance.

The fly wheel, which by persons ignorant of natural philosophy has often been accounted a positive power, in common cases merely equalizes the effect of an irregular force. In using a winch to turn a mill, for instance, a man does not act with equal force all round the circle: but a heavy wheel fixed on the axis resists acceleration and receives a momentum while his action is above par, and returns it again while his action is below par, thus equalizing the movement. And in the common instances of circular motion produced by a crank, as when by the pressure of the foot on a treadle, we turn a lathe or grindstone or spinning-wheel, the force is only applied during a small part of the revolution, or in the form of interrupted pushes, yet the motion goes on steadily, because the turning grindstone, or wheel, or lathe, becomes a fly and reservoir, equalizing the effect of the force. In a steam-engine which moves machinery by a crank, the upward and downward pushes of the piston are converted, by means of a heavy fly-wheel, into a very steady rotatory motion.

A heavy wheel, however, has sometimes been used as a concentrator of force or a mechanic power. By means of a winch, or a weight, or otherwise, motion or momentum is gradually accumulated in the wheel, and is then made to expend itself in producing some sudden and proportionally great effect. Thus a man may lift a very heavy weight by a fly-wheel:—first giving motion to the wheel by turning a winch for a certain number of seconds, and then suddenly hooking a rope to its axle, which rope being wound up on the axle, lifts the weight.

A fly wheel moved in the same manner, and containing the result of a man's action during perhaps one hundred seconds, if made to impel a screw-press will, with one blow or punch, stamp a perfect medal, or form from a rough flat plate of silver a finished spoon, or other utensil.

A spring, in the same sense, may become a mechanical power. A person may expend some minutes in bending it, and may then let fly its accumulated energy in an instantaneous blow. A gun-lock shows this phenomenon on a small scale. The slow bending of a bow, which afterwards shoots its arrow with such velocity, is another instance.

These, then, are the principal means which the solid state of bodies affords us of balancing forces of different intensities. We shall find other such means or mechanic powers belonging to liquids and airs. All of them are of inestimable value to man, by enabling him to accommodate the forces which he can command to any kind of work which he has to perform. Thus he makes his millstone turn with the same velocity, whether it be moved by the slow exertion of a horse or bullock in a ring, or by the quicker motion of a river gliding under the wheel, or by the rapid gush of a water-fall, or by the invisible swiftness of the wind. And again, each of these forces he can equally apply to turn the heavy millstone or to twist a cotton thread.

The wants of men seem first to have led them to use the *simple machines* for the purposes of raising great weights, or overcoming great resistances, and hence they were long called the *mechanic powers*,—particularly the Lever, Wheel and Axle, Plane, Wedge, Screw, and Pulley: but the term conveys to the uninformed a false idea of their real nature, and has begotten the common prejudice with respect to them, that they *generate* force, or have a sort of innate power for saving labour. Now so far is this from being true, that in using them in any case, even more labour or bodily exertion is expended than would suffice to do the work without them. This assertion is intentionally rendered paradoxical to arrest attention, but its truth will appear from the following considerations.

One man may be able, with a tackle of pulleys having ten plies of the rope, to raise a weight which it would require ten men to raise at once without pulleys. But if the weight is to be raised a yard, the ten men will raise it by pulling at a single rope and walking one yard, while the single man at his tackle must walk until he has shortened the ten plies of rope of one yard each; that is, he must walk ten yards, or ten times as far as the ten men did. In both cases, therefore, we have just the same quantity of man's work expended, to accomplish the same end, in the one case performed by ten men in one minute, in the other, by one man in ten minutes; and if the work continues longer, let us say a whole day for the ten men, it will last ten days for the single man, and there will be ten days' wages of a man to pay in both cases: there is, therefore, no saving of human effort from using the pulleys, but a loss, because of the great friction which has to be overcome. Now exactly the same is true of all other simple machines, or mechanic powers; none of them save labour, in a strict sense of the phrase; they only allow a small force to take its time to produce any requisite magnitude of effect.

The real advantages of these machines are such as the following:

That one man's effort, or any small power, which is always at command, by working proportionally longer, will answer the purpose of the sudden effort of many men, even of hundreds or thousands, whom it might be most inconvenient and expensive, or even impossible, to bring together.

A ship's company of a few individuals easily weighs a heavy anchor by means of the capstan.

A solitary workman, with his screw or other engine, can press a sheet of paper against types, so as to take off a clear impression; to do which without the press, the direct push of fifty men would be insufficient; and these fifty men would be idle and superfluous except just at the instants of pressing, which recur only now and then. In this way the screw may be said to do the work of fifty men, for it is as useful here.

A man with a crow-bar may move a great log of wood to a convenient place, where twenty men would have been required to move it without the crow-bar; and although the single man takes twenty minutes perhaps, to do what the many men would have done in one minute, as the twenty might not have been wanted again for the rest of the day, the crow-bar may really be as useful as the twenty men.

It is so important to have correct notions on the subject of the simple machines or mechanical powers, that more space has been here allotted to the explanation of the general principle, than has been usual in such works. After the examination which it has now undergone, however, the author hopes that none of his readers would have difficulty in detecting immediately any common fallacy connected with it;—as that of supposing, for instance, that a lever, or great pendulum, or spring, or heavy fly-wheel, &c. can ever exert more force than has passed into it from some source of motion.

"*By solid connecting parts, also, the direction of any existing motion or force may be changed. Hence the endless variety of* COMPLEX MACHINES." (*Read the analysis at page* 141.)

It is this power of changing the direction of motion, added to the power of adjusting intensities of force by the simple machines last described, which has enabled man to make complex machines, rivalling in their performances the work of human hands. It would be endless to attempt the enumeration of the modes in which the direction of motions may thus be changed, for it would be to enumerate and describe the whole apparatus of the arts and sciences; but we shall advert to a few as specimens.

Straight motion into rotatory.—The straight motion of wind or water becomes rotatory in wind or water-wheels.—The straight-downward pressure of the human foot, acting at intervals on a treadle and crank, turns round the grindstone, and common lathe, and spinning-wheel. The alternate rising and falling of the piston of a steam engine is made, by means of a crank, to turn the great fly-wheel and prime axle of motion.

Rotatory motion into straight.—An axle in turning winds up a rope, and lifts a weight in a straight line.—A crank on a turning axle, if connected with a pump-rod, will work the piston up and down, or it will work a saw.—Pallets or teeth on a turning-wheel act on the handle of a great forge hammer, so that every one in passing produces a blow.

We need not multiply instances. By a visit to great manufacturing towns, or, indeed, by simply directing the eyes to what is passing around, in any part of the civilized world, we discover miracles of mechanic art:—machines driven by wind and water for grinding corn;—machines for sawing wood and giving it various forms;—machines in which rods of metal are seized between great rollers, and are flattened at once into thin plates, as if they were of clay, and these plates again are slit into bars or ribbons;—spinning machines, which perform their delicate office even more uniformly than human hands, forming thousands of threads at once, in obedience to the impulse of a single steam-engine;—weaving machines, which accomplish their difficult task with the most admirable perfection; paper machinery, which converts worn-out and apparently useless remnants of our apparel, into the uniform and beautiful texture of paper, a texture which, with the farther assistance of the pen, or types, or engraved plate, becomes a magic conservatory of mind, shutting up among its folds the brightest effusions of genius, and ready at any instant to disclose them again to the inquiring student, nothing changed after revolving centuries;—coining machinery, which divides and stamps thousands of beautiful medals in an hour, and keeps an exact record of its work;—cranes, —pile engines,—turning lathes,—time-pieces,—all the implements of agriculture, of mining, of navigation, &c. &c. If Aristotle deemed the title or definition of *tool-using animal* appropriate to man two thousands years ago, what title should be given now?

In many of the complex machines, several of the simple ones are found as elements; and in the same machine may be comprised many of the means of changing the direction of motion.

"*Friction.*" (*Read the analysis page* 141.)

In estimating the effects of mechanical contrivances, by the rule of the comparative velocities of the power and resistance, there is an important correction to be made, on account of the friction on each other, of the moving parts. In the steam-engine, where the rubbing parts are numerous, the loss of power from friction often amounts to one-third of the whole.

Impediment from friction seems to be owing to two causes: 1st, a degree of cohesive attraction between the touching substances; 2d, the roughness of these surfaces, even where, to the naked eye, they appear smooth.

It is supposed to be, because the roughnesses, or little projections and cavities, in pieces of the same substance, mutually fit each other, as the teeth of similar saws would, that the friction is greater between such, than between pieces of different substances, with dissimilar grain.

The friction of one piece of iron, wood, brick, stone, &c. on another piece of the same substance, has been measured by making the second piece an inclined plane, and then gradually lifting one end of it, until the upper mass began to slide,—the inclination of the plane, just before the sliding commences, is called the angle of repose.

It is this angle in the substances concerned, which determines the degrees of sloping in the sides of hills composed of sand, gravel, earth, &c. in the sides of canals, the banks of rivers, &c.

If the thread of a screw winds round the spindle with an angle less than this, the screw can never slip or slide back from force acting against its point.

But for friction, men walking on the ground or pavement would always be as if walking on ice; and our rivers, that now flow so calmly, would all be frightful torrents.

The following means are used to diminish friction between rubbing surfaces, and either singly or in combination, according to circumstances.

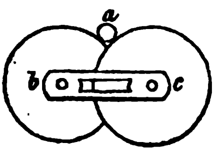
1. Making the rubbing surfaces smooth:—but this must be done within certain limits, for great smoothness allows the bodies to approach so near that a degree of cohesion takes place.

Letting the substances which are to rub on each other be of different kinds. Axles are made of steel, for instance, and the parts on which they bear are made of brass: in small machines, as time-keepers, the steel axles often play in agate or diamond. The swiftness of a skaiter depends much on the great dissimilarity between steel and ice.

3. Interposing some lubricating substance between the rubbing parts; as oils for the metals, soap, grease, black-lead, &c. for the woods. There is a laughable illustration of this, in the holiday sport of soaping a lively pig's tail, and offering him as the prize of the clever fellow who can catch and hold him fast by his slippery appendix.

4. Diminishing the extent of the touching surfaces; as in making the rubbing axis of a wheel very small.

5. Using wheels, as in wheel carriages, instead of dragging a load along the ground. Castors on household furnature are miniature wheels.



6. Using what are called friction wheels;—which still farther diminish the friction even of a smooth axis, by allowing it to rest on their circumferences, which turn with it. Here *a* represents the end of an axis, and *b* and *c* two friction wheels, on which it rests.

7. Placing the thing to be moved on rollers or balls, as when a log of wood is drawn along the ground upon rounded pieces of wood; or when a cannon, with a flat circular base to its carriage, turns round by rolling on cannon-balls laid on a hard level bed. In these two cases there is hardly any friction, and the resistance is merely from the obstacles which the rollers or balls may have to pass over.

Of all rubbing parts the joints of animals are those which have the least friction, considering the strength, frequency, and rapidity of their movements. We study and admire the perfection found in them, without being able very closely to imitate it.

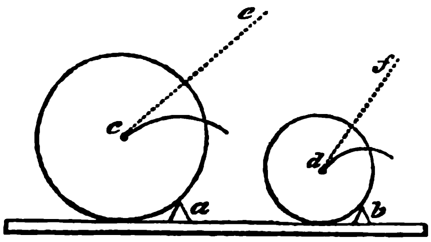
Wheel carriages merit notice here, as illustrating many of the circumstances connected with friction, and moreover as being among the most common of machines.

Wheel carriages have three advantages over the sledges, for which they are the substitutes:

1. The rubbing or friction, instead of being between an iron shoe and the stones and irregularities of the road, is between the axle and its bush, which have surfaces smoothed and fitted to each other, and well lubricated.

2. While the carriage moves forward, perhaps fifteen feet, by one revolution of its wheel, the rubbing part, *viz.* the axle, only passes over a few inches of the internal surface of its smooth greased bush.

3. The wheel surmounts any abrupt obstacle on the road by the axle describing a gently rising slope or curve, as shown in this figure, where *a* represents an obstacle, and the curve at *c* represents the path of the axle in surmounting it. The wheel rises as on an inclined plane, and gives to the drawing animal the relief which such a plane would bring. This advantage of a wheel is proportioned to the magnitude. It is seen that the smaller wheel here represented, has to rise in the steeper

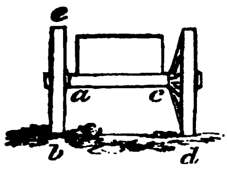


curve from *d*, to surmount the same size of obstacle It is true also, that a small wheel will sink to the bottom of a hole, where a larger one would rest on the edges as a bridge. It is not true, however, according to the popular prejudice, that the large hind-wheels of coaches and wagons help to push on the little wheels before them ; fore-wheels are made smaller, merely to facilitate the turning of the carriage.

From these three causes, the difference in performing the same journey of a mile, by a sledge and by a wheel-carriage, is, that while the former rubs over every roughness in the road and is jolted by every irregularity, the rubbing part of the latter, the axle, glides very slowly over about thirty yards of a smooth oiled surface, in a gently waving line. It is ascertained that the resistance is thus reduced to 1-100th of what it is for a sledge.

On hilly roads, in descending, it is common to *lock* or fix one of the wheels of a carriage; yet it is seen that the horses have then to pull nearly as much, as on a level road with the wheel free; showing the effect of a little increase of friction.

The wheel of a carriage, simple as, from our extreme familiarity with it, it now appears to us, is a thing of very nice workmanship, and which has exercised much ingenuity. It acquires astonishing strength, indeed that of the arch, from what is called its dished form, seen here in the wheel *c*, as contrasted with the flat wheel *a;* a form which is farther useful in this, that when the carriage is on an inclined road, and more of the weight consequently falls upon the wheel of the lower side, the inferior spokes of that wheel become nearly perpendicular, and thereby support the increased weight more safely. When wheels, instead of standing upright, like *a* and *c* shown here, are made to incline outwards, as is common, owing to the ends of the axle-tree being bent down a little, to give a security against the accident of the wheels falling off, the pull to the horses in deep or sandy roads is much increased; for an inclining wheel naturally describes a



curved path, as is seen when a hoop or wheel-barrow inclines; and the horses, in drawing straight forward, therefore, have to overcome this deviating tendency in all the wheels. This source of resistance is still more remarkable when the inclined wheels have broad rims. Such wheels must be of smaller diameter at the outer than at the inner edge, as the end of a cask is smaller than its middle; then, as the iron hoops or tires which cover the different parts cannot all truly measure the same length of road by an equal number of turns, there will be a constant rubbing or grinding forward of the lesser rings, and a grinding backward of the larger, which must injure the road, rapidly wear the iron, and exhaust the strength of the pulling animals. Such wheels rolling free would describe a circle, as is seen when a thimble or drinking glass or sugar-loaf is pushed forward on any plane surface.

The application of springs to carriages, which is an improvement of comparatively recent date, not only renders them soft vehicles on rough roads, but much lessens the pull to the horses. When there is no spring, the whole load must rise with every rising of the road, and must sink with every depression, and the depression costs as much as the rising, because the wheel must be drawn up again from the bottom of it; but in a spring-carriage moving rapidly along, only the parts below the springs are moved in correspondence with the irregularities, while all above, by the inertia of the matter, have a soft and steady advance. Hence the superiority of those very modern carriages, furnished with what are called *under springs*, which insulate from the effect of shocks, all the parts, excepting the wheels and axle-trees themselves. When only the body of the carriage is on springs, the horses have still to rattle the heavy frame-work below it over all irregularities, and the wheels, as well as the structure generally, must be of much greater strength to bear the consequent shocks.

The subject of wheel carriages is interesting to medical men, because it often occurs to them to have to direct in transporting the sick or wounded. And many a medical man practising in an extensive district, or in a large town, is indebted to a well constructed carriage for valuable hours in every day employed in reading or writing.

It is perhaps difficult to conceive any thing more elegant and perfect, than the carriages of modern refinement; and it is no wonder that a man, who contrasts them as seen gliding swiftly along the prepared levels and slopes of our modern landscapes, with the awkward vehicles on the bad roads of former times, should imagine that absolute perfection had at last been obtained. Yet, we are perhaps now on the eve of a farther change, which for many purposes will be of greater importance than all that has yet been achieved, *viz.* the general adoption of rail-roads, with new-fashioned carriages to suit them. It is now widely known that to drag a loaded wagon up one inconsiderable hill, costs more force than to send it thirty or forty miles along a level rail-way; and the conclusion follows, that although the original expense of forming the level line might considerably exceed that of making an ordinary road, still in situations of great traffic the difference would soon be paid for by the savings, and when once paid, the savings would be as profit ever after. To readers conversant with political economy, it would be superfluous to speak here of the advantages of any greater facility of intercourse, but to those who are not, the following reflections may be interesting.

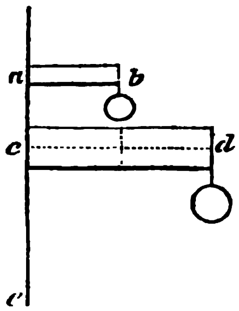
In reviewing the history of the human race, we find every remarkable increase in civilization to have taken place very much in proportion to the facilities of intercourse enjoyed in particular situations: first, therefore, civilization grew along the banks of great rivers, as the Nile, the Euphrates, and the Ganges; or along the shores of inland seas and archipelagos, as in the Mediterranean and the numerous islands of Greece; or over fertile and extended plains, as in many parts of India. The reason it is not difficult to assign. When the situation thus bound a great number of individuals into one body, the useful thought or action of any one unusually gifted, and which, in the insulated state, would soon have been forgotten and lost, extended its influence immediately to the whole body, and became the thought or action of all who could benefit by it; and it was recorded for ever, as part of the growing science or art of the community. In a numerous society, too, such useful new thoughts and acts would naturally be more frequent, because from every person feeling that he had the eyes of the multitude upon him, and that the rewards of excellence would be proportionally great, an emulation would arise in all the pursuits that could contribute to the well-being of the society. Men soon learning to estimate aright these and many other advantages of easy intercourse, after having seized with avidity all the stations naturally fitted for their purposes, began to make new stations themselves, and to improve upon the old: they created rivers and shores and plains of their own, that is, they constructed canals and basins and roads; and thus artificially connected regions which nature seemed to have separated for ever.—In the British isles, whose favoured children have so proudly taken the lead in showing the prodigies which wise policy may effect, the advantages arising from certain lines of canal and road first executed, soon led to numberless similar enterprises, and within half a century the empire has been thus intersected in all directions: and it seems as if the noble work were now to be crowned by the substitution of level rail-ways for many of the common roads and canals. Several of these, of considerable extent, have already been established, and although they and the carriages upon them are far from having the perfection which philosophy says they will admit, the results have been very satisfactory. If we suppose the progress to continue, and the price of transporting things and persons to be reduced by them to a fourth of the present charge—and in many cases it may be less—and if we suppose the time of journeying with safety also reduced in some considerable degree, of which there can be as little doubt—the general adoption of them would effect a very extraordinary revolution and improvement in the state of society. Without in reality changing the distances of places, it would in effect bring all nearer to each other, and would give to every part of the kingdom the conveniences of the whole, of town and country, of sea-coast and of highland district. A man, wherever residing, might consider himself virtually near to any other part, when at the expense of time and money now expended in travelling a short distance, he might travel much farther. The over-crowded and unhealthy parts of towns would scatter their inhabitants into the country; for the man of business could be as conveniently at his post from several miles off, as he now is from an adjoining street. The present heavy charges for bringing produce to market from great distances being nearly saved, the buyer every where would purchase cheaper, and the producer would be still better remunerated. In a word, such a change would be effected as if the whole of Britain had been compressed by magic into a circle of a few miles in diameter, yet without any part losing aught of its magnitude or beauties.—All this may appear visionary: but it is less so than it would have been, seventy years ago, to anticipate what has really come to pass, that the common time of travelling from London to Edinburgh would be forty-six hours. At the opening of the rail-road near Darlington, in 1825, a train of loaded carriages was dragged along by one little steam-engine, a distance of twenty-five miles within two hours; and in some parts of the journey the speed was more than twenty miles an hour: the whole load was equal to a regiment of soldiers, and the coal expended was under the value of a crown. An island with such roads would be an impregnable fortress; for in less time than an enemy would require to disembark on any part of the coast, the forces of the country might be concentrated to defend it.

" *Strength depends on the magnitude, form, and position of bodies, as well as on the degree of cohesion in the material.*" (*Read the Analysis, page* 141.)

The minute details connected with this branch of the subject belong to the practical engineer, but there are some general truths which should be familiar to every body.

Of similar bodies the largest is proportionally the weakest.

Suppose two blocks of stone left projecting from a rock that



has been hewn, of which blocks one, as *d*, is twice as long and deep and broad as the other *b*. The larger one will by no means support as much more weight at its end than the other, as it is larger, and for two reasons. 1st. In the larger, each particle of the surface of attachment at *c*, in helping to bear the weight of the block itself, has to support by its cohesion twice as many particles beyond it in the double extent of projection, as a particle has to support in the shorter block at *a*; and 2dly, both the additional substance, and any thing appended at the outer extremity of the larger, are acting with a double lever advantage to break it, that is, to destroy the cohesion at *c*. Hence if any such projection be carried out very far, it will break off or fall by its own weight alone. What is thus true of a block supported at one end is equally true of a block supported at both ends, and indeed of all masses, however supported and of whatever forms.

That a large body, therefore, may have proportionate strength to a smaller, it must be made still thicker and more clumsy than it is made longer; and beyond a certain limit no proportions whatever will keep it together, in opposition merely to the force of its own weight.

This great truth limits the size and modifies the shape of most productions of nature and of art;—of hills, trees, animals, architectural or mechanical structures, &c.

Hills. Very strong or cohesive material may form hills of sublime elevation, with very projecting cliffs and very lofty perpendicular precipices: and such are seen accordingly where the hard granite protrudes from the bowels of the earth, as in the Andes of America, the Alps of Europe, the Himalayas of Asia, and the Mountains of the Moon in Central Africa. But material of inferior strength exhibits lower summits, [illegible] ranges with more rounded surfaces. The gradation is very striking and constant from granite mountains, down to those of chalk or gravel or sand, that the geologist can generally tell the substance of which a hill is composed by the peculiarities of its shape.

Even in granite itself, which is the strongest of rocks, there is a limit to height and projection; and if an instance of either, much more remarkable than now remains on earth, were by any chance to be produced again, the law which we are considering would prune the montrosity. The grotesque figures of rocks and mountains seen in the paintings of the Chinese, or actually formed in minature for their gardens, to express their notions of perfect sublimity and beauty, are caricatures of nature for which originals can never have existed. Some of the smaller islands in the Eastern Ocean, however, and some of the mountains of the chains seen in the voyage towards China, along the coasts of Borneo and Palawan, exhibit perhaps the very limits of possibility in singular shapes. In the moon, where the weight or gravity of bodies is less than on earth, on account of her smaller size, mountains might be many times higher than on earth—and observation proves that the lunar mountains are in fact much the highest.

By the action of winds, rains, currents, and frost, upon the mineral masses around us, there is unceasingly going on an undermining and wasting of supports, so that every now and then immense rocks, or almost hills, are torn by gravity from the station which they have held since the earth received its present form, and fall in obedience to the law now explained.

The size of vegetables, of course is obedient to the same law. We have no trees reaching a height of three hundred feet, even when perfectly perpendicular, and sheltered in forests that have been unmolested from the beginning of time: and oblique or horizontal branches are kept within very narrow limits by the great strength required to support them. The truth, that to have proper strength the breadth or diameter in bodies must increase more quickly than length, is well illustrated by the contrast existing between the delicate and slender proportions of a young oak or elm, while yet in the seedsman's nursery, and its sturdy form when it has braved for centuries all the winds of heaven, and has become the monarch of the park or forest.

Animals furnish other interesting illustrations of this law.

How massive and clumsy are the limbs of the elephant, the rhinoceros, the heavy ox, compared with the slender forms of the stag, antelope, and greyhound! And unless the bones where made of stronger material than now, an animal much larger than the elephant would fall to pieces from its own weight alone. Many have questioned whether the mammoth, or antediluvian elephant, could have lived on dry land, or must have been amphibious, that its great body might generally be borne up by water. The whale is the largest of animals, but feels not its mighty weight, because lying constantly in the liquid support of the ocean. A cat may fall with impunity, where an elephant or ox would be dashed to pieces.

The giants of the heathen mythology could not have existed upon this earth, for the reason which we are now considering; although on our moon, where, as already stated, weight is much less, such beings might be. In the planet Jupiter again, which is many times larger than the earth, an ordinary man from hence would be carrying in the simple weight of his body, a load sufficient to crush the limbs which supported him. The phrase *a little compact man*, points to the fact that such a one is stronger in proportion to his size than a taller man.

The same law limits the height and breadth of architectural structures.—In the houses of fourteen stories, which formerly stood under the castle of Edinburgh, there was danger of the superincumbent wall crushing the foundation.

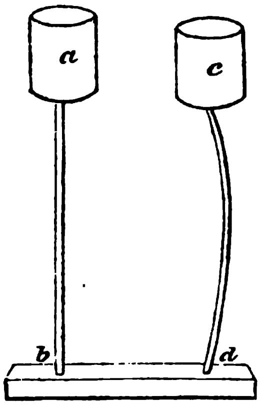
Roofs. Westminster Hall approaches the limit of width that is possible without very inconvenient proportions or central supports; and the domes of the churches of St. Peter in Rome, and St. Paul in London, are in the same predicament.

Arches of a bridge. A stone arch, much larger than those of the magnificent bridges in London, would be in danger of crushing and splintering its material.

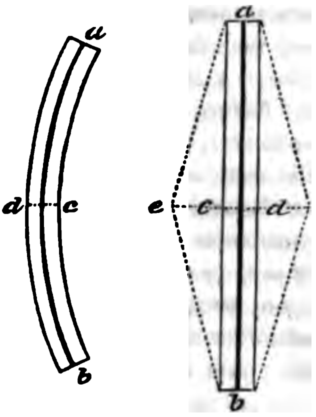
Ships. The ribs or timbers of a boat have scarcely a hundreth part of the bulk of the timbers of a ship ten times as long as the boat. A ship's yard of ninety feet contains perhaps twenty times as much wood as a yard of thirty feet, and even then is not so strong in proportion. If ten men may do the work of a three-hundred-ton ship, many more than three times that number will be required to manage a ship three times as large. Very large ships, such as the two built in Canada, in the year 1825, which carried each nearly ten thousand tons, are weak from their size alone; and the loss of these two first specimens of gigantic magnitude will not encourage to the building of others like them.

The degree in which the strength of structures is dependent on the *form* and *position* of their parts, will be illustrated by considering the two cases of *longitudinal* and *tranverse* compression. And the rule for giving strength will be found to be, to cause the force tending to destroy, to act, as equally as may be, on the *whole* resisting mass, at the same time, and with as little mechanical advantage as possible.

In *longitudinal compression*, as produced by a body *a*, on the atoms of the support *b*, the weight, while the support remains straight, can only destroy the support, by crushing it in opposition to the repulsion and impenetrability of all of its atoms. Hence a very small pillar, if kept perfectly straight, supports a very great weight, but a pillar originally crooked or beginning to bend resists with only part of its strength; for as seen in *c d*, the whole weight above is supported on the atoms of the concave side only, which are therefore in greater danger of being overpressed and crushed, while those on the convex side, separated from their natural helpmates, are in the opposite danger of being torn asunder. The atoms near the centre in such a case are almost neutral, and might be absent without the strength of the pillar being much lessened.



Long pillars or supports are weaker than short ones, because they are more easily bent; and they are more easily bent because a very inconsiderable and therefore easily effected yielding between each two of many atoms makes a considerable bend in the whole; while in a very short pillar there can be no bending without a great change in the relation of proximate atoms, and such as can be effected only by great force. The weight or force bending any pillar may be considered as acting at the end of a long lever reaching from the end as *a* to the centre, against the strength resisting at a short lever from the side *d* to the centre: the strength therefore has relation to the difference between these. Shortness then or any stay or projection, as *a e b*, which, by making the resisting lever longer, opposes bending, really increases the strength of a pillar.



A column with ridges projecting from it, is on this account stronger than one that is perfectly smooth.

A hollow tube of metal is stronger than the same quantity of metal as a solid rod, because its substance standing farther from the centre resists with a longer lever. Hence pillars of cast-iron are generally made hollow, that they may have strength with as little metal as possible.

In the most perfect weighing-beams for delicate purposes, that there may be the least possible weight with the required strength, the arms, instead of being of solid metal, are hollow cones, in which the metal is not much thicker than writing paper.

Masts and yards for ships have been made hollow in accordance with the same principle.

In Nature's works we have to admire numerous illustrations of the same class.

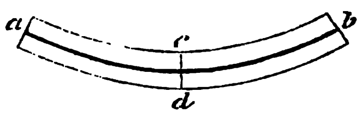
The stems of many vegetables, instead of being round ex-

ternally, are ribbed or angular and fluted, that they may have strength to resist bending. They are hollow also as in corn-stalks, the elder, the bamboo of tropical climates, &c. thereby combining lightness with their strength.—A person who visits the countries where the bamboo grows, cannot but admire the almost endless uses to which its straightness, lightness, and hollowness make it applicable among the inhabitants. Being found of all sizes, it has merely to be cut into pieces of the lengths required for any purpose, and Nature has already been the turner, and the polisher, and the boarer, &c. In many of the Eastern Islands bamboo is the chief material of the ordinary dwellings, and of the furniture,—the fanciful chairs, couches, beds, &c., flutes and other wind instruments there are merely pieces of the reed with holes boared at the requisite distances; conduits for water are pipes of bamboo; bottles and casks for preserving liquids are single joints of larger bamboo with their partitions remaining; and bamboo split into threads is twisted into rope, &c.

From the animal kingdom also we have illustrations of our present subject:—the hollow stiffness of the quills of birds; the hollow bones of birds; the bones of animals generally, strong and hard and often angular externally, with light cellular texture within, &c.

Tranverse Pressure.

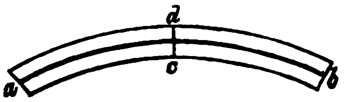
When a horizontal beam is supported at its extremities as at *a* and *b*, its weight bends it down more or less in the middle, the particles on the upper side being compressed, while the parts below are distended; and the bending and tendency to break are greater, according as the beam is longer and its thickness or depth is less.



The danger of breaking, in a beam so situated, is judged of, by considering the destroying force as acting by the long lever reaching from the end of the beam to the centre, and the resisting force or strength as acting only by the short lever from the side to the centre; while only a little of the substance of the beam on the under side is allowed to resist at all. This last circumstance is so remarkable, that the scratch of a pin on the under side of a plank resting as here supposed, will sometimes suffice to begin the fracture.

Because the resisting lever is small in proportion as the beam is thinner, a plank bends and breaks more readily than a beam, and a beam resting on its edge bears a greater weight than if resting on its side. Where a single beam cannot be found deep enough to have the strength required in any particular case, as for supporting the roof of a house, several beams are joined together, and in a great variety of ways, as is seen in house-rafters, &c. which, although consisting of three or more pieces, may be considered as one very broad beam, with those parts cut out which do not contribute much to the strength.

The arched form bears tranverse pressure so admirably, because by means of it the force that would destroy, is made to compress all the atoms or parts at once, and nearly in the same degree.



By comparing this figure with the last, we see that the atoms on the under side of an arch resting against immoveable abutments, as at *a* and *b*, must be compressed about as much as those on the upper side, and cannot therefore be torn, or overcome separately. The whole substance of the arch therefore resists, almost like that of a straight pillar under a weight, and is nearly as strong.

To be able to adapt the curve to the size of an arch and to the nature of the material, requires in the architect a perfect acquaintance with *measures*, &c.

An error, which has been frequently committed by bridge-builders, is the neglecting to consider sufficiently the effect of the horizontal thrust of the arch on its piers. Each arch is an engine of oblique force (see page 181,) pushing the peer away from it. In some instances, one arch of a bridge falling, has allowed the adjoining peers to be pushed down towards it, by the thrust, no longer balanced, of the arches beyond; and the whole structure has given way at once like a child's bridge built of cards.

It is not known at what time the arch was invented, but it was in comparatively modern times. The hint may have been taken from nature, for there are instances in alpine countries of natural arches, where rocks have fallen between rocks, and have there been arrested and suspended, or where burrowing water has at last formed a wide passage under masses of rock which remain balanced among themselves as an arch above the stream. Nothing can surpass the strength and beauty of some modern stone bridges;—those for instance which span the Thames as it passes through London.

Iron bridges have been made with arches twice as large as those of stone, the material being more tenacious, and calculated to form a lighter whole. That of three fine arches, between the city of London and Southwark, is a noble specimen, and compared with the bridges of half a century ago, it appears almost a fairy structure of lightness and grace.

The great domes of churches, as those of St. Peter's in Rome and St. Paul's in London, have strength on the same principle as simple arches. They are in general strongly bound at the bottom with chains and iron-bars, to counteract the horizontal thrust of the superstructure.

The Gothic arch is a pointed arch, and is calculated to bear the chief weight on its summit or key-stone. Its use, therefore, is not properly to span rivers as a bridge, but to enter into the composition of varied pieces of architecture. With what effect it does this, is seen in the truely sublime Gothic structures which still adorn so many parts of Europe.

The following are instances in smaller bodies, of strength obtained by the arched form.—A thin watch-glass bears a very hard push;—a dished or arched wheel for a carriage is many times stronger to resist all kinds of shocks than a perfectly flat wheel;—a full cask may fall, with impunity, where a strong square box would be dashed to pieces;—a very thin globular flask or glass, corked and sent down many fathoms into the sea, will resist the pressure of water around it, where a square bottle, with sides of almost any thickness, would be crushed to pieces.

We have an illustration from the animal frame, of the arched form giving strength, in the cranium or skull, and particularly in the skull of man, which is the largest in proportion to its thickness;—the brain required the most perfect security, and by the arched form of the skull this has been obtained with little weight.—The common egg-shell is another example of the same class; what hard blows of the spoon or knife are often required to penetrate this wonderful defence provided for the dormant life! The weakness of a similar substance, which has not the arched form, is seen in a scale from a piece of freestone which so readily crumbles between the fingers.

To determine, for particular cases, the best forms of beams and joists and of arches, domes, &c., is the business of strict calculation, and belongs therefore to mathematics or the *science* of *measures*.

It was a beautiful problem of this kind, which Mr. Smeaton, the English engineer, solved so perfectly, in the construction of the far famed Eddystone lighthouse. He had, to determine the form and dimensions of a building, which should stand firm on a sunken rock, in the channel of a swift ocean tide, and exposed to the fury of tempests from every quarter.—Only the man who has himself been driven before the irresistible storm in the darkness of night, and in the midst of dangers, and whose eyes have watched the steady ray from the lighthouse which saved him, can appreciate fully the importance of the studies which bring such useful results; or can feel how happy he is to have fellow men, whose talents, although exerted usually for individual good, are yet by God's providence made to accomplish the most philanthropic ends, and to bind the whole of human kind into one great society of helping brotherhood.

ANIMAL AND MEDICAL MECHANICS.

Mechanism of the Human Skeleton.

Having now completed our study of general mechanics, we shall proceed, with the light thence derived, to examine that most interesting illustration of many of the truths—the solid frame of the human body—a perfect work of an unerring Engineer!

There is scarcely a part of the animal body, or an action which it performs, or an accident that can befal it, or a piece of professional assistance which can be given to it, that does not furnish illustration of some truth of natural philosophy; but were we here to enter into much detail, we should be giving minute lessons on anatomy, physiology, surgery, and medicine, instead of explaining general laws. We shall therefore only touch upon as many particulars as will make the understanding of all the others easy; taking care to include among our illustrations, such matters of importance as would be likely to escape the notice of a hasty student.

The *cranium* or *skull* was already mentioned as an instance of the arched form answering the purpose of giving strength. The brain, in its nature, is so tender or susceptible of injury, that slight local pressure disturbs its action. Hence a solid covering like the skull was required, with those parts made stronger and thicker which are most exposed to injury. An architectural dome is constructed to resist one kind of force only, always acting in one direction, *viz.* gravity; and therefore its strength increases regularly towards the bottom, where the weight and horizontal thrust of the whole are to be resisted; but in the skull, the tenacity of the substance is many times more than sufficient to resist gravity, and therefore aids the form to resist forces of other kinds operating in all directions.

When we reflect on the strength displayed by the arched film of an egg-shell, we need not wonder at the severity of blows which the cranium can withstand.

In the early fetal state, that which afterwards becomes the strong bony case of the brain, exists only as a tough flexible membrane. Ossification commences in this membrane, long before birth, at a certain number of points from which it spreads, and the portions of the skull formed around these points soon acquire the appearance of so many scales or shells applied on the surface of the brain, and held together by the remaining membrane not yet ossified. During parturition, these portions overlap at their edges, so as most usefully to diminish the size, and to change the form of the head. They afterwards become firmly fixed together, by projections of bone from each, shooting in among similar projections of the adjoining ones, until all mutually cohere by perfect dove-tailed joints, like the work of a carpenter. These joints are called the sutures of the cranium, an are visible to extreme old age. Through early childhood, the cranium remains to a certain degree yielding and elastic, and the falls and blows so frequent during the lessons of walking, &c. are borne with impunity. The mature skull consists of two *layers* or *tables*, with a soft *diploe* between them; the outer table being very tough, with its parts dove-tailed into each other as tough wood would be by human artificers; while the inner table is harder and more brittle, (hence called *vitreous*,) with its edges merely lying in contact, because its brittleness would render dovetailing useless.

A very severe partial blow on the skull generally fractures and depresses the part, as a pistol-bullet would: while one less severe, but with more extended contact, being slowly resisted by the arched form, often injures the skull by what is correspondent to the *horizontal thrust* in a bridge, and causes a crack at a distance from the place struck,—generally half way round to the opposite side. Sometimes in a fall with the head foremost, the skull would escape injury, but for the body which falls upon it, pressing the end of the spine against its base.

In the lower jaw we have to remark the greater mechanical advantage, or lever-power, with which the muscles act, than in most other parts of animals. The temporal and masseter muscles pull almost *directly*, or at right angles to the line of the jaw, while in most other cases, as in that of the deltoid muscle lifting the arm, the muscles act very *obliquely*, and with power diminished in proportion to the obliquity. An object placed between the back teeth is compressed with the whole direct power of the strong muscles of the jaw. Hence the human jaw can crush a body which offers great resistance, and the jaws of the lion, tiger, shark, and crocodile, &c. are stronger still.

The *teeth* rank high among those parts of the animal body, which appear almost as if they were severally the fruits of distinct miraculous agencies—so difficult is it to suppose a few simple laws of life capable of producing the variety of form so beautifully adapted to purposes, which they exhibit. They constitute an extraordinary set of chissels and wedges, so arranged as to be most efficient for cutting and tearing the food, and with their exterior enamel so hard, that in early states of society, teeth were made to answer many purposes for which steel is used now. It seems, however, as if the laws of life, astonishing as they are, had still been inadequate to cause teeth cased in their hard enamel, to grow as the softer bones grow; and hence has arisen a provision more extraordinary still. A set of small teeth appear soon after birth, and serve the child until six or seven years of age; these then fall out, and are replaced by larger ones, which endure for life; the number being completed only when the man or woman is full-grown, by four teeth, called wisdom teeth, because they come so late, which rise to fill up the then spacious jaw.

The spine or back bone has, in its structure, as much of beautiful and varied mechanism as any single part of our wonderful frame. It is the central pillar of support or great connecting chain of all the other parts; and it has, at the same time, the office of containing within itself, and of protecting from external injury, a prolongation of the brain, called the spinal marrow, more important to animal life than the greater part of the brain itself. We shall see the spine uniting the apparent incompatibilities of great elasticity, great flexibility in all directions, and great strength both to support a load and to defend its important contents.

Elasticity.—The head may be said to rest on the elastic column of the spine, as the body of a carriage rests upon its springs. Between each two of the twenty-four vertebræ or distinct bones of which the spine consists, there is a soft elastic *intervertebral substance*, about half as bulky as a vertebra, yielding readily to any sudden jar; and the spine moreover, is waved or bent a little like an italic *ſ*, as seen when it is viewed sideways; and for this reason, also, it yields to any sudden pressure operating from either end. The bending might seem a defect in a column intended to support weight, but the disposition of the muscles around is such as to leave all the elasticity of the bend and a roomy thorax, without any dimunition of strength.

Flexibility.—The spine may be compared to a chain, because it consists of twenty-four distinct pieces, joined by smooth rubbing surfaces, so as to allow of motion in all directions; and a little motion comparatively between each two adjoining pieces, becomes a great extent of motion in the whole line. The articulating surfaces are so many, and so exactly fitted to each other, and are connected by such number and strength of ligaments, that the combination of pieces is really a stronger column than a single bone of the same size would be.

The *strength* of the spine as a whole, is shown in a man's easily carrying upon his head a weight heavier than himself: while each separate vertebra is a strong irregular ring, or double arch surrounding the spinal marrow. The spine increases in size towards the bottom, in the justest proportion, as it has more weight to bear.

Considering the great number of parts forming the spine, and their so delicate mutual adaptation, one might expect that injuries and diseases of the structure would be very frequent. The reverse, however, is true under natural circumstances; so that while hundreds and thousands of works have been published on the ailments of almost each of the other parts of the body, it is almost within a few years that spine affections have drawn the minute attention of medical men. One reason of this is, that all which regards health and disease is now much more completely analyzed than formerly ; but another and the chief reason is, that from a change recently introduced into the system of education for young ladies, a considerable proportion of them have grown to womanhood with weakened and crooked spines. The subject merits farther consideration here.

To the well-being of the higher classes of animals, exercise of their various parts is as necessary as their nourishment, and if it be withheld by any cause during the period of growth, the body is often permanently crippled, or at least, never acquires its due form and proportions. The overflow of life and energy which nature has given to young creatures, to prompt them to the required exertion, is seen in the ever-changing occupation of a child, the quick succession of its ideas, its jumping and skipping, and using all the modes of round-about action that will expend muscular energy, instead of seeking, as in after-life, to accomplish its desired ends in the shortest ways:—and among the inferior animals, the same truth is illustrated by the play of kittens, puppies, lambs, &c. But, strongly as nature has thus expressed herself upon the important subject of exercise among the young, tyrant fashion, with a usual perversion of common sense, has of late times, in England, formed a school discipline, for young woman of the higher classes, which wars directly with nature's dictate. The consequences have been such, that a stranger arriving here from China, might almost suppose it the design to make crooked and weak spines by our school discipline, as it is the design in China to make little feet by the iron shoe. The result is the more striking, because the brothers of the female victims, and who of course have similar constitutions, are robust, healthy, and well-formed. A *peasant girl*, when her spirits are buoyant, is allowed to obey her natural feeling, and at proper times may dance, and skip, and run, until healthy exhaustion asks that repose, which is equally allowed ; and thus she grows up strong and straight : but the *young* *lady* is receiving constant admonition to curb all propensity to such vulgar activity, and often, just in proportion as she subdues nature, she receives the praise of being *well-bred*. The multifarious studies of the young lady come powerfully in aid of the admonition, by fixing her for many hours every day to sedentary employment. The consequences soon follow, of weakness in the body generally from the want of the natural quantity and variety of exercise, but of the back particularly, from the manner in which the sitting is usually performed. While it would be accounted great cruelty to make a delicate young creature stand all day, because the legs would tire, this very cruelty is in almost constant operation against the back, as if backs could not tire as well as legs. A girl is allowed to sit down because she has been long standing, but great care is taken that the muscles of the back, which still remain in action as she sits, shall not be at all relieved ; for, from the idea that it is ungraceful to loll, she is either put upon a stool which has no back at all, or upon a very narrow chair with a perpendicular back. Now neither of these relieves her spine, yet the stool is less hurtful than the chair, by allowing it to bend in different ways, so as to rest the different sets of muscles alternately, while the chair keeps it constantly upright, and nearly unmoved. The excessive fatigue soon causes the spine to give way in some part and to bend, and the curvature becomes permanent. When a bend has taken place in one situation, there immediately follows an opposite bend above or below, to keep the centre of gravity of the body always directly over the base. Thus the curve becomes double, like an italic *ſ*, and the distortion is complete. In bending, the spine is sometimes also partially rotated, so as to show from behind that waving profile which should be seen only from the side.

In the school discipline now spoken of, when the inclination of the back has once begun, it is very soon increased by the means used to cure it. Strong stiff stays are put on, to support the back as it is said, but which in reality, by superseding the action of the muscles intended by nature as the supports, cause these to lose their strength, so that when the stays are withdrawn they are unable to support the body. Longer sittings in the narrow upright chair are then recommended, and sometimes the back is forcibly stretched by pulleys, or the patient is kept all day and night lying on an inclined board, losing her health, &c. &c. The only things guarded against are the allowing to the child proper exercise and air, and the letting her rest when she is not taking exercise. With many persons the prejudice had at least grown up, that strong stays should be put on at a very early age, to prevent the first approach of the mischief, and that a child should always be made to sit on the straight-backed chair, or to lie on the hard plane: and it is probable, that if these cures and preventives had been adopted as universally and strictly as many deemed them necessary, we should now scarcely have in England a young lady with a back strong enough properly to perform its offices. It would be disgusting to see an attempt made to improve the strength and shape of a young race-horse or greyhound, by binding tight splints or stays round its beautiful young body, and then tying it up in a stall; but this is the kind of absurdity and cruelty which has been so commonly practised in this country, towards what may well be called the most faultless of created beings.

A pernicious prejudice, with respect to this curvature or distortion of the spine, long existed, *viz.* that it was a scrofulous affection; and many mothers concealed it as much as possible, and sought remedy from quacks far from home. Indeed, until within a few years, the management of spine-diseases was chiefly the province of some irregular members of the profession, and a rich source of wealth it became to them, from many of their remedies being calculated to prolong instead of to cure the evil. The practice in spine cases, however; has now fallen into the hands of the profession generally, and science having detected the true causes of the evil, its frequency is already diminished. It has been shown that nothing is easier than to prevent it, and that the best cures are those conducted on the general principles of improving the health of the patient, and of using exercises which directly strengthen the affected part.

Some might except here a long description of machines employed in the treatment of such affections: but fortunately the list of those which are useful or safe is very short:—a sofa to rest upon; choice of pleasant means of taking exercise, such as the skipping-rope, shuttlecock, dumb-bells, a rope-ladder to climb, a winch to turn, &c.;—and, where it is much desired that the young lady should practise music, a chair may be used with crutches rising from its sides, or with straps descending from an overhanging canopy or crane, to support the head and shoulders; the straps being kept tight by proper weights, acting over pulleys in the top and back of the chair. The author, in various cases, has had a small light crane of wood made, which well answers the purpose, and may be attached to a common chair. It would be out of place here to detail those particulars of constitutional treatment, which so usefully aid the effects of suitable exercise.

The Ribs.—Attached to twelve vertebræ in the middle of the back, are the ribs or bony stretchers of the cavity of the chest, constituting a structure which solves, in the most perfect manner, the difficult mechanical problem of making a cavity with solid exterior, which shall yet be capable of dilating and contracting itself. Each pair of corresponding ribs may be considered as forming a hoop, which hangs obliquely down from the place of attachment behind; and so that when the forepart of all the hoops is lifted by the muscles, the cavity of the chest is enlarged.

We have to remark the double connexion of the rib behind, first to the bodies of two adjoining vertebræ, and then to a process or projection from the lower, thus effecting a very steady joint, and yet leaving the necessary freedom of motion; and we see the forepart of the rib to be of flexible cartilage, which allows the degree of motion required there, without the complexity of a joint, and admirably guards, by its elasticity, against the effects of sudden blows or shocks.

The muscles which have their origin on the ribs and their insertion into the bones of the arm, afford us an example of action and re-action being equal and contrary. When the ribs are fixed, these muscles move the arm; and when the arm is fixed, by resting on a chair or other object, they move the ribs. This is seen in fits of asthma and dyspnea.

The human skeleton, with its naked ribs, is so associated in the common mind with ideas of death, and loss of friends, and all the terrors of doubtful futurity, that to most persons it is an object of abhorrence: but to the philosophic mind, which rises superior to place and time, the so admirable adaptation of all the parts to their purposes, and of parts which being purely mechanical are perfectly understood, makes it, independently of all professional considerations, an object of the most intense interest. Such mechanism reveals, by intelligible signs, the hand of the Creator; and a man may be said sublimely to commune with his Maker, who contemplates and understands the structure aright.

The *Shoulder-joint* is remarkable for combining great extent of motion with great strength. The round head of the shoulder-bone rests upon a shallow cavity in the shoulder-blade, that it may turn freely in all ways; and the danger of dislocation from this shallowness is guarded against by two strong bony projections above and behind. To increase the range of motion to the greatest possible degree, the bone called the shoulder-blade, which contains the socket of the arm, slides about itself upon the convex exterior of the chest, having its motion limited only by a connexion, through the collar-bone or clavicle, with the sternum.

The *scapula* or *blade-bone* is extraordinary as an illustration of the mechanical rules for combining lightness with strength. It has the strength of the arch from being a little concave, like the dished wheel already described, and its substance is chiefly collected in its borders and spines, with thin plates between, as the strength of a wheel is collected in its rim, and spokes, and nave.

The bones of the arms, considered as levers, have the muscles which move them attached very near to the fulcra and very obliquely, so that from working through a short distance comparatively with the resistances overcome at the extremities, the muscles require to be of great strength. It has been calculated that the muscles of the shoulder-joint, in the exertion of lifting a man upon the hand, pull with a force of two thousand pounds.

Notwithstanding all the securities to the shoulder-joint now described, in the infinite variety of twists, and falls, and accidents to which men are liable in the busy scene of society, the joint is frequently dislocated, that is, the rounded head of the humerus or arm-bone slips from its socket, with instant lameness as a consequence.

In the treatment of dislocations and fractures of the framework of the human body, the surgeon cannot avoid displaying strikingly either his skill in his profession or his ignorance. With what ease does the displaced arm or thigh-bone return, under the guidance of the skilful hand! and to what horrible, and often unavailing torture, is the victim subjected, when in such a case ignorance dares the attempt! It is positive pain to a vivid imagination to look into the records of ancient surgery and to be made present, as it were, to the stretching of patients on the rack with pulleys and powerful engines, to do what better information could so easily have accomplished without violence, And would that the records of modern times contained fewer instances of individuals crippled for life by such practice. Nothing can now ensure impunity and a quiet conscience to a practitioner in this branch, if he wants a familiarity with the laws of mechanical philosophy, and a perfect knowledge of anatomy.

With our present information on these subjects, we are surprised at the detail of the practices and errors promulgated in former times, owing to ignorance of mechanics, even by authors of the highest credit. It would hardly be believed that Mr. Pott, one of the glories of English surgery, held that in reducing a dislocation of the shoulder or hip, it was useless to pull by the hand or foot, because the intervening joints prevented the strain from reaching the part desired.*

Some surgeons, possessing a certain degree of knowledge in mechanics but only that degree which is dangerous, having heard that the lever was a powerful engine, have tried to replace bones solely by leverage, as it was called. Thus, a man's dislocated arm has been placed over the back of a chair as a fulcrum, or over the top of a door, and while the weight of the suffering body was hanging to it on one side as the resistance, force has been applied to the other side, enough sometimes to break the bone, or to tear away the ligaments and soft parts about the joint.

Other surgeons, after learning in the same way the effects of the pulley, have wished to do all by irresistible extension, and instead of borrowing the moderate assistance which might be useful have torn muscles and ligiments from their attachments.

It is not the object of this work to enter into an extended examination of those accidents befalling the body which require mechanical skill for their proper management, for this would be to deliver a course of instruction on practical surgery; but it is wished to teach the student those valuable general principles which may furnish a constant direction, and may solve most difficulties. Possessing these, and good sense, he will often be a more effective minister of his art than a man full of learned precedents, who wants them. To make this lesson more impressive to his young readers the author takes the occasion to observe, that when he was himself so young that he could not yet have had extensive practical experience, he was thrown into a situation where a heavy medical charge devolved upon him; and where, through accidents among a numerous crew, during an eventful voyage leading to intercourse with the savage inhabitants of unfrequented coasts, within twenty-six months, he had more practice in singular wounds, dislocations, and fractures, then falls to the lot of many practitioners during a whole life. It was then that he became fully aware of the importance to the medical man of general philosophical principles; and his peace of mind after the voyage, was much owing to the circumstances which had made him look carefully at the body through such media.

---

* With due deference to our author, we cannot help thinking, that there will not only be no difficulty in believing this fact, but that assent will be readily yielded to its correctness, in a great measure, if not to its fullest extent. If the intervening joints do not *entirely prevent* the strain from reaching the part desired at least by pulling at the hand or foot in dislocations of the shoulder or hip, we incur a greater probability of producing injury of the elbow or knee joints, than of reducing the luxation. Therefore the rule laid down by Pott "that all force used in reducing the luxated head of a bone" "ought always to be applied to the other extremity of said bone" is a correct one, and based on sound principles; and moreover experience is in its favour.

The os humeri, or bone of the upper arm, is not perfectly cylindrical; but like most of the other bones called cylindrical, it has ridges to give strength, on the principle explained in the chapter "on strength of materials."

The elbow joint is a correct hinge, and so strongly secured that it is rarely dislocated without fracture.

The fore arm consists of two bones with a strong membrane between them. Its great breadth, from this structure, affords abundant space for the origin of the many muscles that go to move the hand and fingers: and the very peculiar mode of connexion of the two bones, gives man that most useful faculty of turning the hand round, into what are called the positions of pronation and supination, exemplified in the action of twisting, or of turning a gimlet.

The old surgeons, who acted frequently by rules of routine rather than by reasons, in the accident of fracture to one or both bones of the fore arm, often applied a tight bandage, which pulled the bones at the fractured part close to each other, and thus injured the future shape and strength of the arm.

The wrist. The many small bones forming this have a signal effect of deadening, in regard to the parts above, the shocks or blows which the hand receives.

The annular ligament is a strong band passing round the joint, and keeping all the tendons which pass from the muscles above to the fingers, close to the joint. It answers the purpose of so many fixed pulleys for directing the tendons: without it, they would all, on action, start out like bow-strings, producing deformity and weakness.

The human hand is so admirable, from its numerous mechanical and sensitive capabilities, that an opinion at one time commonly prevailed, that man's superior reason depended on his possessing such an instructor and such a servant. Now although reason, with hoofs instead of fingers, could never have raised man much above the brutes, and probably could not have secured the continued existence of the species, still the hand is no more than a fit instrument of the godlike mind which directs it.

The pelvis, or strong irregular ring of bone on the upper edge of which the spine rests, and from the sides of which the legs spring, forms the centre of the skeleton. A broad bone was wanted here to connect the central column of the spine with the lateral columns of the legs, and a circle was the lightest and strongest. If we attempt still farther to conceive how the circle could be modified, to fit it for the spine to rest on, for the thighs to roll in, for muscles to hold by, both above and below, for the person to sit on, we shall find, on inspection, that all our anticipations are realized in the most perfect manner. In the pelvis, too, we have the thyroid hole and ischiatic notches, furnishing subordinate instances of contrivance to save material and weight:—they are merely deficiences of bone where solidity could not have given additional strength. The broad ring of the pelvis protects most securely the important organs placed within it.

The hip joint exhibits the perfection of the ball and socket articulation. It allows the foot to move round in a circle, as well as to have the great range of backward and forward motion exhibited in the action of walking. When we see the elastic tough smooth cartilage which lines the deep socket of this joint, and the similar glistening covering of the ball or head of the thigh-bone, and the lubricating synovia poured into the cavity by appropriate secretories, and the strong ligaments giving strength all around, we feel how far the most perfect of man's works falls short of the mechanism displayed by nature.

The thigh bone is remarkable for its projections called trochanters, to which the moving muscles are fixed, and which lengthen considerably the lever by which the muscles work. The shaft of the bone is not straight, but has a considerable forward curvature. Short-sightedness might suppose this a weakness, because the bone is a pillar supporting a weight: but the bend gives it in reality the strength of the arch, to bear the action of the mass of muscle called *vastus*, which lies and swells upon its forepart.

The knee is a hinge joint of complicated structure, and it claims the most attentive study of the surgeon. The rubbing parts are flat and shallow, and therefore the joint has little strength from form; but it derives security from the numerous and singularly strong ligaments which surround it. The ligaments on the inside of the knees resemble, in two circumstances, the annular ligaments of joints, *viz.* in having a constant and great strain to bear, and yet in becoming stronger always as the strain increases. The line of the leg, even in the most perfect shapes, bends inwards a little at the knee, requiring the support of the ligaments; and in many persons it bends very much; but the inclination does not increase with age. The legs of many weakly in-kneed children become straight by exercise alone. This inclination at the middle joint of the leg, by throwing a certain strain on the ligaments, gives an increase of elasticity to the limb, in the actions of jumping, running, &c.

In the knee there is a singular provision of loose cartilages, which have been called friction cartilages, from a supposed relation in use to friction wheels; but their real effect seems to be to accommodate in the different positions of the joint, the surfaces of the rubbing bones to each other.

Under the head of *Pneumatics*, we shall find that the bones forming the knee are held together, independently of the ligaments, by a constant pressure of the atmosphere, amounting to upwards of sixty pounds.

The great muscles on the forepart of the thigh are contracted into a tendon a little above the knee, and have to pass over and in front of the knee to reach the top of the leg, where their attachment is. The tendon, in passing over the joint, becomes bony, and forms the patella or knee-pan, often called the pulley of the knee. This peculiarity enables the muscles to act more advantageously, by increasing the distance of the rope from the centre of motion. The patella is moreover a sort of shield or protection to the forepart of this important joint.

The leg below the knee, like the fore-arm already described, has two bones. They offer spacious surface of origin for the numerous muscles required for the feet, and they form a compound pillar of greater strength than the same quantity of bone as one shaft would have had. The individual bones also are angular instead of round, hence deriving greater power to resist blows, &c

The ancle joint is a perfect hinge of great strength. There is in front of it an annular ligament, by which the greater part of the tendons passing downwards to the foot and toes are kept in their places. One of these tendons passes under the bony projection of the inner ancle, in a smooth appropriate groove, exactly as if a little fixed pulley were there.

The heel, by projecting so far backwards, is a lever for the strong muscles to act by, which form the calf of the leg, and terminate in the tendo achillis. These muscles, by drawing at it, lift the body, in the actions of stånding on the toes, walking, dancing, &c. In the foot of the negro the heel is so long as to be ugly in European estimation; and its great length rendering the effort of smaller muscles sufficient for the various purposes, the calf of the leg in the negro is smaller in proportion than in other races of men.

In a graceful human step the heel is always raised before the foot is lifted from the ground, as if the foot where part of a wheel rolling forward; and the weight of the body supported by the muscles of the calf of the leg, as just described, rests for the time on the fore part of the foot and toes. There is then a bending of the foot in a certain degree. But where strong wooden shoes are used, or any shoe so stiff that it will not yield and allow this bending of the foot, the heel is not raised at all until the whole foot rises with it, so that the muscles of the calf are scarcely used, and in consequence soon dwindle in size, and almost disappear. Many of the English farm servants wear heavy stiff shoes; and in London it is a striking thing to see the drivers of country wagons, with fine robust persons in the upper part, but with legs which are fleshless spindles, producing a gait most awkward and unmanly. The brothers of these men, and who are otherwise employed, are not so mis-shapen. What a pity that, for the sake of a trifling saving, fair nature should be thus deformed. An example of an opposite kind is seen in Paris. There, as the streets have no side pavements, and the ladies have consequently to walk almost constantly on tiptoe, the great action of the muscles of the calf has given a conformation of the leg and foot, to match which the Parisian belles proudly challenge all the world,—not aware, probably, that it is a defect in their city to which the peculiarity of their form is in part owing.

A person confined to bed for a week or two by sickness, has generally to remark a much greater wasting of the legs than of the arms; the reason of which is, that the muscles of the leg in ordinary cases, being more in use than those of the arms, have their bulk so much owing to this, that they suffer greater change from inaction than the others.

Facts of this kind, and the known truth that, by gymnastic exercises and training, the form of the body may be much changed, bear directly on the subject at present so near the hearts of many English mothers, *viz.* the weak and crooked backs of their daughters.—Strong stays, which in part supersede the action of the muscles placed by nature around the spine to support it, cause these muscles to dwindle in size, and afterwards, when the support of the stay fails or becomes unequal, the back bends or twists. Stays, therefore, can neither help to make strong and well-formed backs originally, nor can they be a remedy after the weakness has commenced. A healthy young woman from the country, with the spine lying deep between the firm cushions of muscle which suppport it, if taken and braced up in tight stays, according to town fashion, will frequently exhibit at the end of a short time such a wasting of the flesh that the points of the bone in the spine may be counted by the eye, all the way down.

The arch of the foot is to be noticed as another of the many provisions for saving the body from shocks by the elasticity of the supports. The heels, and the balls of the toes, are the two extremes of the elastic arch, and the leg rests between them.

Connected with elasticity, it is interesting to remark how imperfectly a wooden leg answers the purpose of a natural leg. With the wooden leg, which always remains of the same length, the centre of the body must describe, at each step, a portion of a circle of which the bottom nob of the leg is the centre; and the body is therefore constantly rising and falling;—while with the natural legs, which, by gentle flexure at the knee, are made shorter or longer in different parts of the step as required, the body is carried along in a manner perfectly level. In like manner, a man riding on horseback, if he keep his back upright and stiff, has his head jolted by every step of the trotting animal; but the experienced horseman, even without rising in the stirrups, by letting the back yield a little at each movement, as a bent spring yields during the motion of a carriage, can carry his head quite smoothly along.

In a general review of the skeleton, we have to remark, 1st, the nice adaptation of all the parts to each other, and to the strains which they have respectively to bear; as in the size of the spinal vertebræ increasing from above downwards—the bones of the leg being larger than those of the arm, and so on. 2dly, the objects of strength and lightness combined; as by the hollowness of the long bones—their angular form—their thickening and flexures in particular places where great strain has to be borne—the enlargement of the extremities to which the muscles are attached, lengthening the lever by which these act, &c. 3dly, we have to remark the nature and strength of material in different parts, so admirably adapted to the purposes which the parts serve: there is a bone, for instance, in one place nearly as hard as iron, where, covered with enamel, it has the form of teeth, with the office of chewing and tearing all kinds of matter used as food; in the cranium, again, bone is softer, but tough and resisting; in the middle of long bones it is compact and little bulky, to leave room for the swelling of the muscles lying there; while at either end it is large and spongy, with the same quantity of matter, to give a broad surface for articulation; and in the spine the bodies of the vertebræ, which rest on an elastic bed of intervertebral substance, are light and spongy, while their articulating surfaces and processes are very hard. In the joints we see the tough elastic smooth substance called cartilage covering the ends of the bones, defending and padding them, and destroying friction. In infants we find all the bones soft or gristly, and therefore calculated to bear with impunity the falls and blows unavoidable at their age; and we see certain parts remaining cartilage or gristle for life, where their elasticity is necessary or useful, as at the anterior extremities of the ribs. About the joints we have to remark the ligaments which bind the bones together, possessing a tenacity scarcely equalled in any other known substance; and we see that the muscular fibres, whose contractions move the bones and thereby the body,—because they would have made the limbs clumsy even to deformity had they all passed over the joints to the parts which they have to pull,—attach themselves at convenient distances, to a strong cord called a tendon, by means of which, like a hundred sailors at a rope, they make their effort effective at any distance. The tendons are remarkable for the great strength which resides in their slender forms, and for the lubricated smoothness of their surfaces. Many other striking particulars might be enumerated, but these may suffice.—Such, then, is the skeleton or general frame-work of the human body—less curious and complicated perhaps than some other parts of the system which we have yet to examine, but so perfect and so wonderful, that the mind which can attentively consider it without emotion, is in a state not to be envied.*

Note to the Second Edition.

* A distinguished member of our profession, who seems often to have contemplated the human frame under the aspect which elevates the thoughts towards the

The living force of man has been used as a working power in various ways, as in turning a winch—pulling at a rope—

Creator, has lately published, with the title of *Animal Mechanics*, and as a part of the *Library of Useful Knowledge*, an essay on the perfection of design manifested in the animal structure. It has been eulogized in many of the public prints, by friends of the diffusion of knowledge, as one of the most admirable productions of modern times; and in consequence has already been demanded by the public to the extraordinary extent of about thirty thousand copies. On comparing this new essay with the present section of the Elements of Physics, to which it has close relation in title, matter, and arrangement, it will be found to have substituted for the detail of certain of the facts adduced here as striking evidences of creative contrivance, an elaborate exposition, constituting nearly half its substance, of what its author has deemed instances of still more profound design than had hitherto been noticed, and still more striking examples, therefore, of God's wisdom and power. Had these instances appeared to me in the same light, it would have been my agreeable task to have incorporated them with the matter of this second edition: but they do not; yet the wide diffusion of the essay, and the authority with which it has come before the public, make it imperative on me, as a faithful teacher, to notice them here, and to state my opinion, that with respect to every one of them the author has fallen into an extraordinary misapprehension of the true nature of his subject, and has attributed to the Creator contrivance or design which is far from being divine. I publish my remarks without hesitation as regards either the author, or the public-spirited society of which he is a member, assured of their approval, if the remarks are well-founded; but I feel that I shall be doing a kind of sacrilegious violence to many amiable minds, by undeceiving them as to what they have deemed so excellent. The feeling with which the essay is written so naturally interests good men, and the whole is rendered so plausible by the appearance which runs through it of ultra-minute acquaintance with the subject, that thousands of intelligent persons must have yielded up their judgment to the persuasive writer, and must have studied the work with unmixed delight. These are not reasons, however, for concealing the truth, and certainly there is no need to twist or exaggerate truth, for the purpose of proving from the structure of the human body, the wisdom and benevolence which presided at the creation.

The following are part of the errors alluded to. One at least vitiates each chapter.

CHAP. I. *On the Head.*

The author, after stating as usual that the skull has the strength and advantages of the arched form, but not aware apparently that there are kinds of arches so distinct from each other, as to have even direct opposition in certain respects of proportion, &c., hopes to prove the singular perfection of design in the skull, by showing that it has the peculiarities of the architectural arch, or that of bridges, domes, &c; and he expresses wonder that men should have been so long in learning to build domes, when every individual carried in his head a model planned by the unerring Architect! Now the architectural arch has material, form, proportions, &c.

walking in the inside of a large wheel to move it, as a squirrel or turn spit dog moves his little wheel, &c. Each of these has

calculated to resist the force of gravity only, which is unceasing, and acting only, in one direction, and which moreover is essential to the stability of the arch, for if this come to incline a little from its natural position, or be shaken by an earthquake, it is instantly demolished. On the other hand, there is the arch of a cask, or barrel, egg-shell, or cocoa-nut, &c., in which the tenacity of the material is many times greater than necessary to resist the influence of gravity, and comes in aid therefore of the curve, to resist forces of other kinds, approaching in all directions, as in falls, blows, unequal pressure, &c. Now the skull, which may be called the oviform shell of the brain, with the face and mouth attached to its under side, is truly an arch of the latter kind, and having very much oftener to bear pressure and blows coming upon it laterally, than from above. A thimble, bee-hive, limpet-shell, &c. are much nearer approximations to the dome than the skull is, because, like the dome, they are open in one direction, yet by reason of their smaller size and the tenacity of their material, they are perfect, without the peculiar securities of the dome. What a mistake then was it for our author to suppose himself proving the perfection of the skull, by trying to exhibit in it peculiarities which, had they really existed, would have been just so many faults!

Chap. II.—*On the Spine.*

Our author holds, that an important analogy exists between the spine and the mast of a ship. Now supposing that there had been some useful lesson obtainable by comparing the crooked, pliant, every where moveable spine, with the straight, rigid, singularly steadied mast, it will perhaps appear that he was not likely to draw it forth, owing to his imperfect acquaintance with naval matters, as proved by the following assumptions, all of which are errors and yet all are points or parts of his argument:—that the foremast of a ship being very upright, and far forward, causes the vessel to *tack* or *stay* the better—that the main and mizen-masts are made to *rake* or incline backwards, to diminish the danger to them from the forward pitching of the ship—that masts are *sprung* or broken chiefly by coming into contact with the deck when the rigging is too slack:—that certain boats are the fittest of all to withstand storms, because they are without decks, and therefore cannot injure their masts in the way above alluded to. Our author must have been singularly deceived in some way with respect to these matters, as he may learn by applying to any intelligent seafaring man.

Chap. III.—*On the Chest.*

To prove a hitherto concealed perfection here, he asserts that the elasticity bestowed on the cartilages of the ribs is capable of maintaining respiration, and thereby life, in cases where the respiratory muscles have become too weak to perform their office aright—just as if he were to say, that a spring applied to a pump-handle would continue to lift water, or at least would help, after the worker's arms were tired.

some particular advantage; but that mode in which, for many purposes, the greatest effect may be produced, is for the man

CHAP. IV.—*On the Limbs.*

Having mentioned the admirable fact, first pointed out by Borelli, that when a bird sinks down into the sleeping attitude on the branch of a tree, the bending of the limbs so tightens the sinews of the talons, that the foot grasps the branch firmly without the attention or muscular exertion of the animal; he wonders that a similar fact in the human body should have been so long overlooked, *viz.* that when a standing person changes from the soldier's attitude of *attention* to that of *stand at ease*, the bending of the knee and sinking of the pelvis on one side, lifts the other side of the pelvis so as to tighten a ligament or fascia which passes from it to the knee-pan below, and so keeps the leg straight without the fatigue of muscular exertion. Now this is altogether an error. The true reason why the straightened leg requires no muscular support is, that the knee falls a little behind the general line of the leg, and causes the strain to come upon the posterior ligaments of the joint. And proving that there is no tightened fascia, as assumed, between the pelvis and knee-pan, the latter remains quite loose and moveable—yea, even if the distance between the pelvis and knee-pan be still further increased by bending the knee whilst standing on the other leg.

CHAP. V.—*On the Cordage or Tendons.*

In the attempt to prove the tendons to be constructed with consummate skill, he has accumulated many errors. Setting out from the known fact that when a broken rope is spliced, that is to say, has its ends again united by being interwoven with each other, it rarely breaks a second time at the junction; but, not adverting apparently to the circumstance of the rope at that part being double, 1st, he assumes, as a general truth, that plaited ropes are stronger then twisted ropes—contrary to the fact, as is known to every rope-maker; for, what then prevents their plaiting all their ropes instead of twisting them? 2d, He next assumes that the fibres of the tendons are interwoven or plaited, because thereby stronger:—the fact being, however, that they are parallel, although, when torn asunder laterally, a remaining adhesion at a few points may give the appearance of crossing fibres. 3d, He seems not to have been aware that a rope, whether plaited or spliced, will bear much less weight than its constituent fibres loaded singly—the reason being, that in no rope can the tension of the fibres be made so equal that each shall bear its exact share of the load. Plaiting and twisting therefore are defects, and are forced upon men only because the fibres of which ropes are composed are shorter than the ropes, and must be made to cohere, either by being knotted together or by the lateral friction of plaiting or twisting. The chains or wires of a suspension-bridge, which reach from end to end, are neither plaited nor twisted together, which would much weaken them, but are merely secured in parallel contact, as the fibres of long animal tendons also truly are.

The treatise, which we have been obliged thus to criticise, we believe was hastily written, and that the plan was changed more than once in its progress. This will account for its being so little like the valuable other works from the same source.

to carry up to a height his body only, and then to let it work by its weight in descending. A bricklayer's labourer would

Note to the Third Edition.

I introduced the foregoing note reluctantly, for I knew the treatise examined to be from the pen of Mr. Charles Bell. It would have given me much pleasure to have had rather to speak of his high professional merits, or of some acts of professional charity which at my request he had performed, not less honourably to his generosity than to his skill. I had tried to avoid the necessity, first, by telling him of the errors, with a view to correction in subsequent editions of his work; and afterwards, when during his absence from town it was published without alteration, by representing the matter to a leading member of the *Society for the Diffusion of Useful Knowledge*. This gentleman deemed it necessary for me to publish my note. From the resemblance of the treatise to parts of my work, many persons believed it to be mine, and it was bound up with my volume. I was accordingly blamed for the errors by those who discovered them; or believed to sanction the opinions by those who did not; and by some who knew it to be Mr. Bell's, and believed it faultless, the differences between it and mine were thought defects in mine. By allowing it then to remain uncorrected and unnoticed, I should have allowed error extensively to prevail on subjects which I professed to explain, and I should probably have narrowed the circulation and utility of my own work. The errors would have been grave, coming from a professed writer on physics, while they were comparatively venial, appearing as they did; for the attentive study of physics had not yet been insisted upon in our systems of professional education. Had Mr. Bell spoken to me on the subject while writing his essay, my future notice of it would probably have been unnecessary: and the opportunity for so speaking was given, as a copy of my work, which he had done me the honour to accept, lay upon his table, and at some of my visits, had been the subject of conversation to us.

Mr. Bell could not desire to mislead the public, and therefore could not regret that any published error of his should be corrected. Some friend of his, however, has taken offence at the above criticism, as appears by the eighth number of the "*Medical Gazette;*" and has hoped to serve Mr. Bell, not by disproving the alleged errors, for he does not even touch upon them, but by charging the author of the "Elements of Physics," with "ignorance,"—"utter incapacity,"—"being a dangerous guide," &c. on the strength of what he supposes three faults, discovered by him in other parts of that work. As his skill in physics, however, seems not to have enabled him to perceive error where it was, the fact of his supposing error where it was not, need not surprise. Accordingly the three portions of the work deemed erroneous by him, *viz.* the illustration of the strength of the scapula, at p. 213, and the proposals of the *Dilator* and *Pneumatic Tractor*, in the last section, are such as I should be pleased to have accounted even favourable samples, and tests of my fitness for the undertaking. I am happy to have to state, that the suspicion that Mr. Bell himself was the author of the attack, is quite unfounded; for he wrote to me on the subject, saying, "the only thing I am anxious about is that you should not suppose I have authorised the counter-statements."

be able to lift twice as many bricks to the top of a house in the course of a day, by ascending the ladder without a load and raising bricks of nearly his own weight over a pulley each time in descending, as he can by carrying bricks and himself up together, and descending again without a load, as is still usually done.

Reflection would naturally anticipate the above result, independently of experiment, for the load which a man should be

---

The same defender of Mr. Bell explains the strong resemblance between Mr. B's. work and mine (which led to the charge of plagiarism in the *Lancet*,) by saying that I had taken the whole from previous works of his. This is nearly as if a friend of any English lexicographer should charge all who write English with copying from his friend's Dictionary; and even if they had used some other. It was not from Mr. Bell's book of Anatomy that I had studied the structure of the human body; and in the present instance I read from the skeleton alone. There is no remark in the few pages of my work which have so unexpectedly to me become thus matter of discussion, which should not occur to almost any person versed in physics, while contemplating the human skeleton. The originality of my essay was in the selection, condensation, and arrangement, under the title (which I believe was new) of *Animal Mechanics* of some of the most obvious anatomical facts, and in referring these to the physical laws which it was the object of my volume to unfold. That Mr. Bell soon after should have come so near me in these respects, I consider a commendation of my work, and his claiming originality for his own, and not mentioning in his list of previous writings on the subject, mine, which contained the substance of his, except the errors, may have been owing to the hurry with which his was printed, or to his thinking the matter, as in truth it is, of trifling importance.

The same writer further charges it against me, that my reflections on the spine and its diseases, which have been copied from my work into many of the periodicals, are an abstract, unacknowledged, of the late Mr. John Shaw's work on the subject. I should be pleased to think that in my four paragraphs on spinal diseases, I had so happily accomplished, as this censure would imply, the object aimed at throughout my volume, of condensing useful matter; but the fact is, that the paragraphs in question are very nearly the substance of my remarks habitually given to patients under spine disease, before Mr. Shaw's work appeared. My respect for Mr. Bell had led me, from hearing it reported by others, that he descanted ingeniously on the anatomy of the skull, to find room, where few names appeared, for a special commendation of his labours; and had I felt myself called upon, I should not have been behind in regard to Mr. Shaw, for whom, in common with all who knew him, I felt much regard. Mr. Shaw had lent me the skeleton from which in the course of Lectures, of which the present volume records a part, I gave my demonstrations; and which lectures he, with some of Mr. Bell's and his pupils, did me the honour to attend.

portion of the skull in trepanning, has a jointed fulcrum attached to it. Care should be taken to place this fulcrum where its pressure cannot be injurious.

The *circular* or *crown saw* of the trephine, should be worked with a quick motion and gentle pressure, for the reason given at page 178, when treating of cutting instruments. The object is thereby sooner and better attained, and the head of the patient is less shaken.

For the same reason, there is less jarring and an easier division of the bone in amputations, when a light and quick motion of the straight saw is used.

In using the amputation knife, the speed, neatness, and success of the operation, are all favoured by blending the drawing or saw motion of the knife, with the pressure towards the bone.

These last observations are of a hundred similar, which might be made to prove the vital importance to a surgeon of having familiarity with the use of tools or instruments. Perhaps a person cannot better acquire this, than by practising, while young some amusing work of carpentry. Manual dexterity, and a little readiness at mechanical contrivance, so frequently prove of importance to persons in all stations, that a great defect in systems of general education is the not cultivating them with greater attention. If a handless or awkward man embrace the medical profession, and unfortunately attempt to practise surgery or midwifery, although possessed of brilliant intellect, he will very often fail where another would succeed.

The Tooth Key is an instrument found in the hands of most persons who pretend even to the lowest degree of skill in the healing art: and there is perhaps scarcely a day passing, in which teeth are not broken and jaws splintered, and gums bruised even to sloughing, by the unskilful or awkward use of it. The common tooth key may be regarded in the light of a wheel and axle; the hand of the operator acting on two spokes of the wheel to move it, while the tooth is fixed to the axle by the claw, and is drawn out as the axle turns. The gum and alveolar process of the jaw, form the support on which the axle rolls. The common errors in tooth-drawing by the key, are these:

1st. Turning the key towards that side, where the adjoining teeth are so close that the tooth to be drawn cannot pass, without either breaking one of them, or being broken itself. Sometimes two teeth are thus moved instead of one.

2d. Neglecting the natural inclination of the tooth. By winding the tooth round in the direction in which it already inclines, and in accordance with a bend which is generally found in it, the operation is easy and safe; but if it be drawn in the opposite way, it not unfrequently breaks or splinters the part of the jawbone in which it sticks.

3d. If the tooth-claw be blunt, its point may slip upon the tooth, so as to produce an action which is very apt to break the tooth.

4th. Unless the axle or fulcrum of the key be made to rest as evenly as possible on the gum, it will tear or very much injure the gum. It should rest, if possible, over the part of the bone in which the tooth is set, for otherwise—as when a back tooth is drawn with the instrument resting on a part considerably anterior to it—the twist produced is painful, and there is danger of splintering.

A man whose studies or reflection have suggested these remarks, and who then operates leisurely a few times on the dead subject, will often be able to give instant and safe relief to most intense suffering. And it is hardly excusable in any medical man who may be placed where a dentist cannot be procured, to neglect acquiring a talent so easy.

Some dentists pull teeth directly out by a strong forceps made for the purpose; others use a forceps in the manner of the tooth key, by resting one side of it on the gum as a fulcrum. In this case the resting side is formed like the bolster of a tooth key. But much more in all cases depends on the dexterity of the operator than on the form of the instrument.

Steel Trusses for ruptures are one of the blessings to suffering humanity which modern ingenuity has supplied. From the unhealthy employments of some men in society, and the early dissipation or unnatural modes of life of others, debilitated constitutions are frequent, and are often transmitted to offspring; and one of the lamentable effects is that weakness of the flesh forming the sides of cavities, which at particular points allows the protrusion of the living parts from within, so as to form tumours under the skin. The occurrence is called *hernia* or *rupture:* the most common hernia is that of the intestines, through the groins.

Formerly this occurrence disabled for life. A man who had hernia was discharged from the army or navy; he could not ride on horseback, or take usual exercise; he could not lift a weight, and in a word, he often became a miserable burden to himself and others. Now, by fitting the pad of a good steel truss to the part, the rupture is as perfectly restrained, as if the hand of a skilful surgeon were constantly there. The truss may be put on and off, with as little reflection or trouble as a part of the ordinary dress, and the man becomes again almost as fit for all the duties of life as if he were without his ailment.

The old form of the steel truss was that of a half or three-quarter hoop, so bent and tempered, that when put upon the patient, one end, which had a pad upon it, pressed with a given force on the opening by which the rupture protruded. The defects in this kind of truss are, the difficulty of making it to fit exactly; its being rather troublesome to put on and off; and its pressing disagreeably all round the body.

The other kind of truss, free from these defects, consists of a little more than half a hoop, with a pad at each end: one of the pads supports the weakness, and the other rests upon the centre of the back, to bear all the strain there, while the hoop itself reposes loosely on the side of the body. This truss may be called self-adjusting, for it almost falls into its place of itself, and needs no fastenings; the same truss fits all persons of one size, whatever their shape; and the strength may be adjusted by changing the number of plates in the spring-hoop.

Tourniquets, crutches, splints, &c. &c. are so simple in all respects as not to merit special notice here.

This section contains some of the reflections which occur to a person familiar with mechanical philosophy, in contemplating the human skeleton; and the more complete such a person's knowledge is of anatomy, physiology, surgery, and medicine, the more numerous will be the professional objects on which this philosophy will shed a light dissipating doubt and error. The author has not entered into more minute detail, because it would have been encroaching upon the office of the teachers of particular departments, and because he thinks that any one who is not enabled, by the examples here given, to make the applications of the general laws to all possible cases, may account the study of the healing art unsuited to the faculties with which he is endowed.

PART III.

THE DOCTRINE OF FLUIDS. (Read the synopsis, page 41.)

SECTION I.—HYDROSTATICS.

ANALYSIS OF THE SECTION.

The particles in a fluid mass are freely moveable among each other, so as to yield to the least disturbing force. Hence:

1. *In fluid submitted to compression, the whole mass is equally affected, and the compression operates in all directions.—A given pressure, for instance, made by a plug forced inwards upon a square inch of the surface of a fluid confined in a vessel, is suddenly communicated to every square inch of the vessel's surface, however large, and to every inch of the surface of any body immersed in the fluid.*
2. *In any fluid, the particles that are below bear the weight of those that are above, and there is, therefore, a pressure within the mass, increasing exactly with the perpendicular depth and not influenced by the size, or shape, or position of the containing vessel.*
3. *The open surface of a fluid is level; and if various pipes or vessels communicate with each other, any fluid admitted to them will rise to the same level in all.*
4. *A body immersed in a fluid displaces exactly its own bulk of it, which quantity having been just supported by the fluid around, the body is pressed upward with force exactly equal to the weight of the fluid displaced, and must sink or swim according as its own weight is greater or less than this. By comparing therefore the weight of a body with the force which holds it up in a fluid (which is the weight of its bulk of that fluid,) the comparative weights, or the* specific gravities, *are found.*

"Fluid."

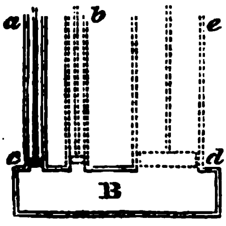
It was explained in the first part, that the same atoms may exist in the form of a solid or of a fluid; and as a fluid, they may either constitute a dense liquid like water, or a light elastic mass like air. A pound of ice, or a pound of water, or a pound of steam, differ only in the particles being more or less distant from each quires to be gone into apart, and forms the branch of the subject called *Pneumatics.*

"In a quantity of fluid submitted to compression, the effect is equally diffused throughout the whole, and similarly in all directions. A given pressure, therefore, made upon an inch of the surface of a fluid confined in a vessel, as by a plug forced inwards, is suddenly felt or borne by every inch of the surface of the vessel, however large, and by every inch of the surface of any body immersed in the fluid."

This truth is of great importance, both from its explaining so many remarkable phenomena of nature, and from the useful applications of it in the construction of machinery.

When a man compresses in his hand a bladder full of air, he readily conceives that the air is not at all more compressed immediately under his fingers, than in every other part of the bladder; and of course that every part of the bladder's surface must be pressing the air as much as those parts on which his fingers rest, and must be bearing a re-action or resistance of the air in an equal degree: and that every single particle of air must be acted upon on every side, so that if a small opening be made any where in the bladder, the air will issue from it with equal readiness. This is in accordance with the characteristic of fluidity, "that the particles glide about among each other almost without friction, so that a particle can never be at rest unless when equally pressed in all directions."

In like manner, if a close vessel B be filled with water, and into the top of it a tube *a c* be screwed, and if then, by means of a cork or moveable plug in the tube at *c*, the surface of the water in the vessel be pressed upon with a force of one pound, the water throughout the whole will be condensed in proportion to the pressure, and every other portion of the vessel B, of equal surface with *c*, will be keeping up the condensation just as

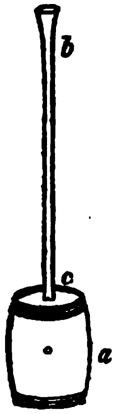


much as *c*, and will be bearing the resistance or elasticity of the water to the extent of one pound. And if there were another similar tube *b*, also with a plug, screwed into the top of the box B, the force of one pound depressing the plug *c* would push up the plug *b* with the same force: and if there were many other similar tubes and plugs, by acting on one, all would be equally affected; and a plug or piston of double size would be twice as much affected as the smaller one; and a plug *d*, of ten times the size, would be lifted with a force of ten pounds. Hence it appears that, through the medium of confined fluid, a force of one pound, acting upon an inch square of the fluid surface in a vessel, may become a bursting force of ten or a hundred or a thousand pounds, according to the size of the vessel, or may be used as a mechanical power to overcome a force much more intense than itself.

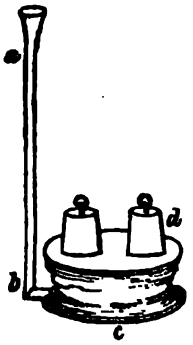
If in the above figure the tube *a* were just such as to contain one pound of water, the plug *c* might be withdrawn from it, and the tube being then filled with water, the same pressure or condensation would take place in the box B as when the plug was pressed with the force of one pound; and of course exactly the same effects would follow on the sides of the vessel and on the other pistons; and if in the other tubes also, water were substituted for the pistons, it is evident that, to balance, it would require to stand as high in them as in the tube *a c*, producing the same level in all, whatever their size.

The fact that the weight of one pound of water may be made through the medium of extended fluid to produce a pressure of hundreds or of thousands of pounds, has been called the hydrostatic paradox; yet there is nothing in reality more paradoxical in it than that one pound at the long end of the lever should balance ten pounds at the short end: indeed it is but another means, like the contrivances called mechanical powers, described in the last chapter, of balancing different intensities of force, by applying them to parts of an apparatus which move with different velocities. Hence the tube *a* being ten times smaller than the tube *e*, the piston in *a* must descend ten inches to raise the greater piston in *e* one inch.

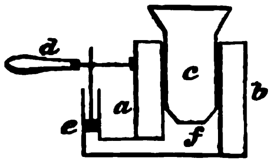
This law of fluid pressure is rendered very striking in the experiment of bursting a strong cask by the weight or action of a few ounces of water. Suppose a cask *a* already filled with water, and that a long small tube *b c* is screwed tightly into its top, which tube will contain only a few ounces of water; by pouring these few ounces into the tube, the cask will be burst. In explanation of this, it is unnecessary to say more than that if the tube have an area of a fortieth of an inch, and contain, when filled, half a pound of water, this produces a pressure of half a pound upon every fortieth of an inch all over the interior of the cask; which is more than a common cask can bear.



The same effect is seen in what is called the *hydrostatic bellows*. It consists of a long small tube *a b*, into which water is poured to enter the body of the apparatus at *c*, which resembles the common bellows, in having wooden boards above and below, and strong leather connecting them. If the tube *a b* holds an ounce of water, and has itself only one-thousandth of the area of the top of the bellows, an ounce of water in the tube will balance weights of a thousand ounces placed on the top of the bellows at *d*. If mercury were substituted in this machine for water, the effect would be fourteen times greater, because mercury is fourteen times heavier in the same bulk: and if a man stand on a large bellows, he may raise himself by blowing into the tube with his mouth.



Mr. Bramah applied this property of fluids in the construction of his singularly powerful and useful *hydraulic press:* in which he merely substituted a strong forcing pump for the lofty tube of the bellows, and a barrel and piston for the leather and boards. It consists, then, of a short and very strong pump-



barrel *a b*, (shown here in section) with a solid piston *c* of proportionate strength, which piston is pushed against the thing to be compressed, by water driven into the barrel beneath, at *f*, from the small pump *e*. If the small pump have only one-thousandth of the area of the large barrel, and if a man, by means of its lever handle *d*, press its piston down with a force of five hundred pounds, the great piston will rise with a force of one-thousand times five hundred pounds, or more than two hundred tons. Scarcely any substance can withstand the power of such a press, whether used to condense, to raise great weights, or to tear things asunder against the most powerful resistance.

The Dilator is a surgical instrument of extensive application, of which the action depends on the principle of the communication of fluid pressure. It was proposed by the author some years ago, and was brought to great practical perfection by his brother, Dr. James Arnott (now superintendant surgeon in the service of the Hon. East-India Company,) in whose publications on diseases of the urethra, &c. it is minutely treated of. Many professional men in this country doubted of its power, from not being aware of the nature of fluid action: but it is in reality a kind of hydraulic press, allowing the operator to act with the most gentle or most energetic force. Further remarks are made upon it in the medical section which follows this chapter.

"*In any fluid, the particles that are below bear the weight of those that are above, and therefore there is a pressure among them increasing in exact proportion to the perpendicular depth, and not influenced by the size, or shape, or position of the containing vessel.*"

Where the atoms have gravity, it is evident that the upper layer must be supported by the second, and this with its load by the third, and the third with its double load by the fourth, and so on. This truth is experimentally proved by putting different heights of liquid into an upright tube, of which the bottom is closed by a flap having a spring or lever to support it, and to indicate the force acting on it. And what is true of the entire column of water in the tube, is true of any single line of atoms in that column; just as it would be true of a line of bricks piled one above another, and maintained upright.

A tube of which the area is an inch square, holds, in two feet of its length, nearly a pound of water; hence, the general truth, well worth recollecting, that the pressure of water at any depth, whether on the side of a vessel or on its bottom, or on any body immersed, is nearly one pound on the square inch for every two feet of depth.

The striking effects from the increase of pressure in a fluid, at great depths, are of course most commonly exhibited at sea. The following instances will illustrate them.

If a strong square glass bottle, empty, be firmly corked, and then sunk in water, it is generally crushed inwards by the pressure, before it reaches a depth of ten fathoms.

A man thus let down in a cask of air, would soon be drowned by the water bursting in upon him.

When a ship founders near the shore, on breaking up, the wreck generally floats, and is cast upon the beach; but when the accident happens in deep water, the great pressure forces water into the pores of the wood, and makes it so heavy that no part can ever rise again to reveal her fate.

A bubble of air or of steam, set at liberty far below the surface of water, is small at first, and gradually enlarges as it rises.

A man who dives deep, suffers much by the compression of his chest, from the elastic air within yielding under the strong pressure. This limits the depth to which divers can safely go.

It is not known whether there is a limit to the pressure which fishes can bear with impunity, but they are chiefly found living in the shallower waters on coasts, or on banks in the midst of the ocean, such as the banks of Newfoundland, the Dogger-bank, and other fishing stations out at sea. In rounding the Cape of Good Hope, at a considerable distance from land, ships pass over the bank of Lagullas, where a hook let down with a bit of red rag as a bait, immediately secures its codfish.

The readiest mode of proving the compressibility of water is, by letting a prepared vessel down into the deep sea. Suppose the vessel to be made with only one entrance through a small round opening, into which, instead of a cork, a sliding rod has been closely fitted. If the vessel be filled with water, and the rod be then inserted in the opening, on sending it down into the sea, the pressure around will push the rod into the vessel, in a degree proportioned to the yielding or compression of the water within: and if there be a stiff-sliding ring on the rod, or some other contrivance to indicate on its return how far it had been driven inwards, the apparatus will serve to show the degree of compression at any depth. At a thousand fathoms it is about one-twentieth of the bulk.

The following are proofs of the pressure in any part of an open fluid, operating in all directions, as already described in the case of a confined fluid.

A bottle-cork carried far under water, is not flattened as if by an unequal pressure, but is reduced in all its dimensions, so as to appear a phial cork.

If a corked empty bottle be sent down into the sea, the cork is forced inwards at a given depth, without regard to the direction in which the mouth of the bottle may happen to point.

If a vessel containing water have an opening in the side, covered by a valve or flap so contrived as to tell the force acting to keep it close, we find that the water tends to escape just as powerfully through such an opening as through one in the bottom, with the same elevation of water over its centre. And different equal openings in the side of a vessel require to be closed with forces exactly proportioned to the heights of liquid above their centres.

In an open square-sided vessel full of water, the whole pressure on any upright side is just half of what it is on an equal extent of horizontal bottom; because the centre of the side is just half as deep as the bottom, and the pressure at the middle being only half as much as at the bottom, and above the middle being just as much less than half, as below it is more than half, it amounts to an exact half in the whole. By nearly the same reasoning it is easy to show, that to support a sluice or flood-gate by pressure at a single point on the outside, the pressure must be made at one-third from the bottom. The knowledge of these facts becomes a rule in the construction of large vessels, canal embankments, &c.

The pressure on a given extent of the side of a narrow vessel is just as great as on the same extent of the side of a wide vessel which has the same depth of fluid: because, as now explained, it depends entirely on the extent of surface acted upon and the depth of liquid.

A flood-gate or sluice which shuts out the ocean, as in docks opening to the sea, bears no more pressure than if it stood only against a lake or river, with the water at the same elevation; and if two immense flood-gates were placed so near to each other as to enclose between them only a few hogsheads of water, they would still be bearing as much pressure as if the Atlantic were resting against them.

Hence the fear is unfounded which many have expressed, in speaking of the project of forming a canal between the Red Sea and the Mediterranean, that because the first is twenty feet higher than the other, it might burst through the flood-gates, and carry devastation along its course.

A deep crevice in a rock, when filled by a shower, is often the cause of the rock being torn asunder, and of part being precipitated.

Extensive walls or faces of masonry, intended to confine banks of sand or earth, if no openings were left for water to escape from behind them, would be burst after rain, unless they had the strength of flood-gates of the same size. Ignorance of this danger has led to some extraordinary catastrophes.

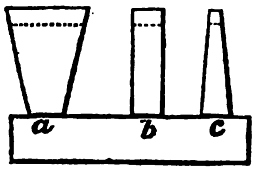
Other examples of the pressure in fluids being in all directions, and proportioned to the depth, are;—the swelling and bursting of leaden pipes when filled from a very elevated source:—the tearing up of the covering of a subterranean drain or water-course, when any accident choaks it near its lower opening, or when the flood is such as to fill it:—the violence with which water enters by an opening or leak near the keel of a deep-floating ship:—the great strength required in the lower hoops and securities of those casks, called vats, used by porter brewers, some of which contain many thousand barrels of liquid.

In speaking of the pressure of a fluid in all directions, some persons have difficulty in conceiving that there is an upward, as well as a downward and a lateral pressure. Now, if in a fluid mass, the particles below had not a tendency upwards proportioned to the pressure around them, from which they are trying to escape, they could not support the fluid above, which entirely rests upon them. Accordingly, if a long tube, open at both ends, and with a sliding plug or piston in it near one end, be partially plunged into water by that end, the water is found to press the plug upwards with force proportioned to the depth to which the plug is carried, and exactly equal to the force with which the water presses upon the bottom or side of a vessel at the same depth, and with which it would press other plugs in other branches of the tube projecting in all directions. On removing such a plug altogether, the upward pressure is visibly proved and measured by the column of water which is pushed into the tube from below, and is there supported, to the level of the water around.

The pressure in a mass of fluid, is proportioned to the perpendicular depth, and is not at all influenced by the size, shape, or position of the containing vessel.

A body immersed in the water of a lake, one foot under the surface, is just as much pressed upon, as if it were one foot under the surface of the sea, and no more than if it were one foot under the surface of a small cistern.

Suppose vessels differing from each other in form and capaci-



ty, as sketched here at *a*, *b*, and *c*, but all having flat bottoms, of exactly the same area; if fluid be poured into all of them to the same level or perpendicular height, as represented here by the dotted line, although the quantity be very different in each, the pressure on the bottom will be the same in all. This truth is easily proved experimentally, by having the bottoms moveable, and held to their places by weights or springs capable of measuring the pressure: or by letting the three vessels all communicate with another vessel of water below them, and then observing that the water in all has still the same level.—These results are other exemplifications of the truths, "*pressure equal in all directions,*" "*pressure as depth,*" and "*pressure as the extent of surface.*" For as a column of the fluid resting on the middle of each bottom just presses with its whole weight, and therefore according to its altitude, this column could not remain at rest if there were any greater or less pressure than its own near it; then as the fluid really is at rest in all the cases, and in all a central column is of the same height, the pressure must be equal on all the bottoms. The case of the largest vessel *a* is in a degree illustrated by supposing it to be filled with upright rods of glass or pieces of smooth cane; only those pieces which rested on the bottom, could press directly on it, while the others would be supported by the oblique sides of the vessel, and by the lateral resistance of the pieces around them.

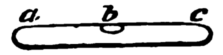
"*Level surface of a fluid.*" (*Read the analysis.*)

That the surface of a fluid must be level, follows from the facts of all the particles being equally attracted towards the centre of the earth, and being perfectly moveable among themselves. The particles forming the surface may be regarded as the tops of so many columns of particles, supported by a uniform resistance or pressure below; and therefore a higher column must sink and a lower one must rise, until just balanced by those around; that is, until all become alike. Besides this, just as a ball rolls down a slope or inclined plane, so do the particles of a fluid slide or move from any higher situation among themselves, to any lower situation unoccupied near them.

A perfectly level surface on earth, really means one in which every particle is equi-distant from the centre of the earth, and it is therefore truly a spherical surface; but so large is the sphere, that if a slice of it of two miles in diameter were cut off, and laid on a perfect plane, the centre of the slice would only be eight inches higher than the edges. Any small portion of it, therefore, for all common purposes, may be accounted a perfect plane.

So truly smooth does a fluid surface become, that it forms a perfect mirror; that is, it reflects or throws back the rays of light which fall upon it so exactly in the order which they had on leaving the object, that an eye which receives them may fancy the object to be placed in the direction of the mirror.—It was over the glassy surface of the fountain or the lake, that the shepherdesses of the young world bent themselves, to learn the charms which nature had bestowed on them.—And a child contemplates with wonder and delight, through the window of a still pool or gliding stream, another sky appearing below the ground, with its clouds, and sun or stars; and another landscape, with inverted woods and mountains, the supposed dwelling of fairy beings.

In the cutting of canals, the making of rail-ways, and in many other operations of engineering, it is of essential importance to determine the level or horizontal direction at any place: and this is usually done by a tube of glass *a c*, filled with spirit except one bubble of air *b*, and called a spirit level. When this tube is horizontal, the bubble has no tendency to move to either end; but if the tube inclines ever so little, the bubble rises to the end which is highest; or, to speak quite correctly, the denser spirit falls down to the lower end, and forces the light bubble away from it. Such a tube properly fixed in a



frame, with a telescope attached to it, or simply with sight-holes to look through, becomes the engineer's guide in many of his most important operations.

A hoop surrounding the earth would bend eight inches in every mile. In cutting a level canal, therefore, which may be considered as part of a hoop, there must be every where a falling from the straight level line, in the proportion now described.

Canals leading from seaports to the interior of countries have generally to ascend; but as water cannot become stagnant in any channel that is not level, the canal is divided, by gates and sluices, into portions at different levels, like steps of a stair, the rising at the joinings being generally from six to twelve feet. The boat is raised or lowered from one level to another by the contrivance called a lock, which is merely a portion of the low level capacious enough for the boat to lie in, furnished with high walls, and with floodgates at both ends; and when the gates below are shut and water is gradually admitted from above, the lock becomes part of the high level, ready as such to deliver a boat, or receive one; and when the upper floodgates are shut, and the water as gradually allowed to escape from the lock, it becomes again a part of the low level, and a boat may enter it or leave it by its lower gates.

The cutting of canals is one of the great items in the mass of modern improvement, which both marks and hastens the progress of civilization. Adverting to the importance of easy intercourse, as explained in a former section, we need only say here that a horse which can draw one ton with difficulty on our best roads, can draw thirty tons with the same speed in a canal-boat.

And what a glorious triumph to science and art it is, to be able to conduct vessels of all kinds, even those originally intended for the ocean surge alone, through the quiet valleys of an interior country! In Scotland, at present, along the Caledonian canal, a noble frigate may be seen, wandering as it were among the inland solitudes, and displaying her grace and majesty to the astonished gaze of the mountain shepherd: and when she has traversed the kingdom, and visited the lonely lakes, whose waters until now had borne only the skiff of the hunter, she descends again by the steps of her liquid stair, and safely resumes her place among the waves.

It is in contemplation at present to lead a ship canal across the isthmus which joins North and South America. The elevation to which the canal must reach, to surmount the central ridge, is considerable, and will increase the difficulty; but such important consequences would follow the accomplishment of the object, that with the continuance of general peace, and the increase of political wisdom, it will probably be attained. If so, the loaded vessel, rising from the Atlantic, would soon be descried among the mountain heights, and a few hours after, would be safely lodged in a port of the opposite sea, having performed, by a near cut, a voyage which at present costs months of delay and hazard, in a tedious navigation round the whole southern continent.—And if the Red Sea and Mediterranean were joined in the same way, as has also been proposed, it would, in effect, bring India nearer to Europe, and would more and more strengthen the bonds of mutual utility and brotherhood among the nations of the earth. Then indeed, might it be said with truth, that the world is a great garden, which has been given to man for his abode, of which every spot has its peculiar sweets and treasures, but the cultivator of each exchanging a share of what he produces for shares in return from others, the same general result follows, as if every field or farm contained within itself the climates and soils and capabilities of the whole globe.

In a canal, the least deviation from the true level would immediately cause any water admitted into it to flow towards the low end. This flux to a lower situation is what is going on in the myriads of streams, which render the face of the earth a scene of such varied beauty and incessant change.

As in the animal body, from even the minutest point, a little vein, endowed with living power, takes the blood which has just brought life and nutriment to the part, and delivers it into a larger vein, whence it passes into larger still, until at last, in the great reservoir of the heart, it meets the blood returned from every part of the body: so in this terrestrial globe, where the magic moving power is simply fluid seeking its level, from every point of the surface, does the rain, which falls to sustain vegetable and animal life, and to renovate nature, glide into a lower bed, and from thence into a lower still, until the countless streams, after every variety of course, combine to form the swelling rivers, which return the accumulated waters into the common reservoir of the ocean. In the living body, the arteries carry back the blood with renewed vitality to every point whence the veins had withdrawn it, and so complete the circulation; and in what may be called the living universe the circulation is completed by the action of heat and of the atmosphere, which from the extended face of the ocean, raise a constant exhalation of watery vapour of invisible purity, which the winds carry and deposit as rain or dew on every spot.

A very slight declivity suffices to give the running motion to water. Three inches per mile, in a smooth straight channel, gives a velocity of about three miles per hour. The Ganges, which gathers the waters of the Himalaya mountains, the loftiest in the world, at eighteen hundred miles from its mouth, is only eight hundred feet above the level of the sea—that is, about twice the height of St. Paul's Church in London; and to fall these eight hundred feet, in its long course, the water requires more than a month. The great river Magdalena, in South America, running for a thousand miles between two ridges of the Andes, falls only five hundred feet in all that distance. Above the commencement of the thousand miles, it is seen descending in rapids and cataracts from the mountains. The gigantic Rio de la Plata has so gentle a descent to the ocean, that in Paraguay, at the distance of fifteen hundred miles from its mouth, large ships are seen which have sailed against the current all the way, by the force of the wind alone: that is to say, which on the beautifully inclined plane of the stream, have been lifted even by the soft wind, to an elevation greater than of our loftiest spires.

A small lake or extensive mill-pond, with very uneven bottom, if suddenly emptied by a sluice or opening at its lowest part, would exhibit a vast number of pits or pools of various size and shape left among its inequalities. But supposing rain to continue falling, or frequently to recur, a remarkable change would soon be effected. In consequence of each pool discharging over its lowest part, that is, sending out a streamlet either into another lower pool, or into a channel leading directly to the sluice or opening, there would be a constant wearing of the part or side over which the water were running, that is to say, a deepening of the breach or channel, and the water in the pool would be consequently becoming shallower, while at the same time the bottom would be filling up with the sand or mud washed down by the rain from the elevations around; and these two operations continuing, the pool would at last altogether disappear. By this change going on in every pool through the whole of the emptied mill-pond, the bottom would at last exhibit only a varied or undulated surface of dry land, with a beautiful arrangement of ramifying channels, all sloping with a precision unattainable by art, to the general mouth or estuary.—The reason that in the supposed case, and in every other, a water-course soon becomes so singularly uniform, both as to dimension and descent, is, that any pits or hollows in it are filled up by the sand and mud carried along in the stream, and deposited where the current is slack; while any elevations are worn away by the action of the more rapid current which accompanies shallowness.

The above paragraph describes in miniature, what has been going on over the general face of our earth, ever since that convulsion of nature which produced its present form. In many places the phenomenon is already complete; in others it is only in progress. The whole of what is now dry land, has at some period been under water, and much of it has evidently been a gradual deposition from water. By some extraordinary convulsion, therefore, our present continents and islands must have been thrown up from the bottom of an ocean, or an ocean must have subsided away from them; and in either case the land must have emerged as chequered and unsightly, as the bottom of the emptied lake supposed above. And it is the gradual operation of *water seeking its level,* which has gradually converted the earth into the paradise which we now behold.

The marks of the former state of the world, and of the progressive change, are every where most strikingly evident to the enlightened eye of philosophy. The present kingdom of Bohemia, for instance, is the bottom of one of the great lakes which once covered Europe. It is a basin or amphitheatre, formed by circular ridges of mountains, and the only gate or opening to it, is that remarkable one by which the water now escapes from it, and which has evidently been cut or formed gradually by the action of the running stream. As the bottom became uncovered by the sinking of the water, and by the formation of a regular sloping channel from every part, the former lake was converted into a fine and fertile county, a fit habitation for man; and the continued drain from it, produced by the rains which fall over its surface, and either pass suddenly away, or sink into the earth and ooze again more gradually in the form of springs, is the beautiful river which we now call the Elbe.

In Switzerland, even now many of the valleys which were formerly lakes, have the opening for the exit of water so narrow, that, as happened in one of them a few years ago, a mass of snow or ice falling into it, converts the valley once more into a lake.

On the occasion alluded to, the accumulation of water within was very rapid; and although, from the danger foreseen to the country below if the impediment should suddenly give way, every means was tried to remove it gradually, the attempt had not succeeded when the frightful burst took place, and involved all below in common ruin.

The magnificent Danube is the drain of a chain of basins or lakes, which must at one time have discharged or run over one into another, but the continued stream cutting a passage at last low enough to empty them all, they are now regions of fertility, occupied by civilized man, instead of the fishes which held them formerly. This operation is still going on in all the lakes of the earth. The lake of Geneva, for instance, although confined by granite rock, is cutting and lowering its outlet, and the surface has fallen considerably within the period of accurate observation and records; and as, at the same time, the wearings of the neighbouring mountains, brought down by the winter torrents, are filling up its bed, if the town of Geneva last long enough, its inhabitants will have to speak of the river in the neighbouring valley, instead of the picturesque lake which now fills it. Already several other towns and villages, which were close upon the lake a century ago, have fields and gardens spreading between them and the shore.

Illustrative of this subject, it is very interesting to observe the contrast between the pure blue water of the Rhone issuing from the lake of Geneva, and the turbid streams which join its course a little farther down. The torrents which fall into the lake all around, are generally charged with the *debris* or wearings of the mountains; but in the still bosom of the lake having deposited all their load, the pure water alone escapes to form the river. On the other hand, the streams coming to the Rhone directly from the Alps, bring their charge of broken-down earth with them; and even after they have joined it, they are long distinguishable by their muddy waters. It is the mud deposited as here described, which is gradually filling up this and other lakes, and which has formed the vast regions of flat country seen about the mouths of most great rivers.

There are some lakes on the face of the earth which have no outlet towards the sea,—all the water which falls into them, being again carried off by evaporation alone—and such lakes are never of fresh water, because every substance, which, from the beginning of time, rain could dissolve in the regions around them, has necessarily been carried towards them by their feeding streams, and there has remained. The great majority of lakes, however, being basins constantly running over at one part towards the sea, although all originally salt, have in the course of time become fresh, because their only supply, being directly from the clouds, or from rivers and springs fed by the clouds, is fresh, while what runs away from them must always be carrying with it a proportion of any substance that remains dissolved in them. We thus see how the face of the earth has been gradually washed to a state of purity and freshness fitting it for the uses of man, and why the great ocean necessarily contains in solution all the substances that originally existed near the surface of the earth, which water could dissolve:—*viz* all the saline substances. The city of Mexico stands in the centre of one of the most magnificent plains on the face of the earth, 7,000 feet above the level of the sea, and surrounded by sublime ridges of mountains, many of them snow-capped. One side of the plain is a little lower than the other, and forms the bed of a lake, which is salt for the reasons stated above;—but the lake will not long be salt, for it now has an outlet. About 150 years ago an extraordinary increase of the lake took place, and covered the pavements of the city; an artificial drain was then cut from the plain of Mexico, about sixty miles from the city, to the lower country external to the plain. This soon freed the city from the water; but becoming every year deeper by the wearing effects of the since uninterrupted stream, it is still lowering the surface of the lake, is daily rendering the water less salt, and is converting the vast salt marches which formerly surrounded the city, into fresh and fertile fields.

The immense continent of Australasia, or New Holland (larger than Europe,) is supposed by some to have been formed at a different time from what is called the old world, so different and peculiar are many of its animal and vegetable productions; and the idea of a later formation receives some countenance, from the immense tracts of marshy or imperfectly drained land which have been discovered in the interior, into which rivers flow, but seem not yet to have worn down a sufficient outlet or discharging channel towards the ocean.

Where the soil or country through which a water-track passes is not of a soft consistence, to allow readily the wearing down of higher parts, and the filling up of hollows by deposited sand, lakes, rapids, and great irregularities of current remain. We have, for instance, the line of lakes in North America, the rapids of the St. Lawrence, and the stupendous falls of Niagara, where, at one leap, the river gains a level lower by one hundred and sixty feet. A softer barrier than the rock over which the river pours, would soon be cut through, and the line of lakes would be emptied.

The contemplation of the fact, that water in seeking its level is constantly wearing where it rubs, and carrying the abraded portions down to lower levels, and ultimately to the bed of the ocean, brings irresistibly the awful idea, that this earthly abode of ours, owing to natural causes already in operation, can have but a limited existence in its present state. No shower falls that does not send some portion of mountain or plain into the depths of the ocean, and thus cause a corresponding encroachment by the rising water; and with revolving ages, unless new convulsions of nature disturb the progress, or art succeed, as in Holland, and elsewhere, to shut out the ocean from extensive low tracks by means of sea dykes or embankments, the dry land must at last disappear, and another gradual deluge must embrace the globe.

There is, perhaps, nothing which illustrates in a more striking manner the exact accordance of nature's phenomena with the few general expressions or laws which describe them all, than the perfect level of the ocean as a liquid surface. The sea never rises or falls in any place, even one inch, but in obedience to fixed laws, and therefore its changes may generally be foreseen and allowed for. For instance, the eastern trade-winds and other causes force the water of the ocean towards the African coast, so as to keep the Red Sea about twenty feet above the general ocean level; and the Mediterranean is a little below that level, because the evaporation from it is greater than the supply of its rivers,—causing it to receive an additional supply by the Strait of Gibraltar; but in all such cases, the effect is as constant as the disturbing cause, and therefore can be calculated upon with confidence.

Were it not for this perfect exactness, in what a precarious state would the inhabitants exist on the sea-shores and the banks of low rivers! Few of the inhabitants of London, perhaps, reflect, when standing close by the side of their noble river, and gazing on the rapid flood-tide pouring inland through the bridges, that although sixty miles from the sea, they are placed almost as low as persons sailing upon its face, where perhaps at the time there may be tossing waves, covered with wrecks and the drowning.

The horrible destruction that would follow any alteration in the level of the ocean, may be judged of by the effects of occasional floods, produced by rains and melting snow in the interior of countries, or by these combined with winds and high tides on the coasts. The flood at St. Petersburgh, in 1825, was dreadful, in which strong westerly winds had retarded the flow of the Neva so much that the water rose forty feet (the height of an ordinary house) above its usual mark, covered all the low parts of the town, and destroyed thousands of human beings.

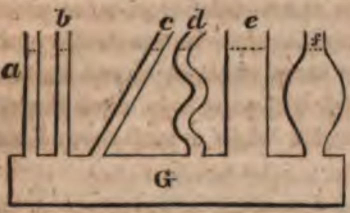
In Holland, which is a low flat, formed chiefly by the mud and sand brought down by the Rhine and neighbouring rivers, much of the country is really below the level of the common spring tides, and is only protected from daily inundation by artificial dykes or ramparts, made strong enough to resist the ocean. What awful uncertainty would hang over the existence of the Dutch, if the level of the sea were subject to change: for while we know the water of the ocean to be seventeen miles higher at the equator than at the poles, owing to the centrifugal force there of the earth's rotation; if the level, as now established, were from any cause to be suddenly changed but ten feet, millions, of human beings, would be the victims.

Where inundation is regularly periodical, as in the Nile, the hurtful effects can be guarded against, and it may even become useful, by fertilizing the soil.

Tracts of land in contact with rivers, and having an elevation between the levels of ebb and flood tide, may be kept constantly covered with water, by surrounding them with dykes, and opening the sluices at high water only; or they may be kept constantly drained, by opening the sluices only at low water. A vast extent of rice fields near the mouths of rivers in India and China are managed in this way, the admission or exclusion of water being regulated by the age of the rice plant.

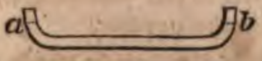
"If various tubes and vessels communicate with each other, fluid admitted to them will rise to the same level in all." (*Read the analysis, p.* 236.)

The adjoining sketch may represent a variety of tubes and vessels, fixed upon and opening into the cistern or box G. Water poured into any one would fill the box, and would then rise to the same level in all. The dotted lines from *a* to *f*, may represent the surfaces of the fluid in the different vessels. in the figure at page 238, it was seen why in all upright cylindrical vessels, as *a*, *b*, and *e*, the fluid rises to the same level: and the figure at p. 246, explained why shape of vessel cannot affect the level. Although in the oblique vessel *c*, represented here, there is more water than in *a*, still there is the same pressure at the bottom of both, because *c* supports part of the weight of its contained fluid on the principle of the inclined plane.

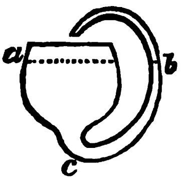


If a tube twenty miles long, and rising and descending among the inequalities of a country, were nearly filled with water, and could have its ends brought together for comparison, it would exhibit two liquid surfaces having precisely the same level, and on either end being raised, the fluid would sink in it to rise in the other.

An easy mode of determining a level line at any spot is to have an open tube, bent up at its ends, and nearly filled with liquid: by then looking along the two surfaces, or through floating *sights* resting on them, an observer looks in a line quite horizontal.



If there were two lakes on adjoining hills of different heights, a pipe of communication descending across the valley and connecting them, would soon bring them to the same level; or if one were much lower than the other, it would empty the one into the other.



A projector thought that the vessel of his contrivance, represented here, was to solve the renowned problem of the perpetual motion. It was goblet-shaped, lessening gradually towards the bottom until it became a tube bent upwards at *c*, and pointing with an open extremity into the goblet again. He reasoned thus: A pint of water in the goblet *a*, must more than counterbalance an ounce which the tube *b* will contain, and must therefore be constantly pushing the ounce forward into the vessel again at *a*, and keeping up a stream or circulation, which will cease only when the water dries up. He was confounded when a trial showed him the same level in *a* and in *b*.

A glass tube inserted into the bottom of an open cask or cistern of any sort, and then bent upwards to appear on the outside like a barometer tube, shows by the elevation of the fluid in it, the height of the greater mass within.

In like manner a tube brought from a river into a neighbouring cellar or pit, indicates the height of the water in the river.

A knowledge of the truth, that water in pipes will always rise again to the height or level of its source, has enabled us in modern times to construct those admirable systems of iron pipes, which distribute water in great towns. The water being brought to any elevated site in or near the town, may be delivered from a reservoir there, by the effect of gravity alone, to every cistern which is under the level of the reservoir; the result not being affected by the pipes having to rise over heights and to descend into valleys many times in their course.

On the hill north of London, on which Pentonville stands, there is a reservoir to which water is brought from Hertfordshire, by a channel cut for the purpose upwards of thirty miles in length, and called the New River. Another reservoir has very lately been constructed at Primrose Hill, by the West Middlesex Water Company, higher than any house in town. It is filled by the operation of steam-engines at the Company's works near Hammersmith, five miles off. It will supply water to the summits of all the houses connected with it, and may be exceedingly useful in cases of fire.

Many have believed that the ancients were ignorant of the law, that fluid in pipes will rise to the level of its source, because in all the ruins of their aqueducts, the channel is a regular slope. Some of these aqueducts, as works of magnitude, are not inferior to the great wall of China, or the Egyptian Pyramids; yet at the present day, a single pipe of cast-iron is made to answer the same purpose, and even more perfectly. It is now ascertained, however, that it was not ignorance of the principle, but want of fit material for making the pipes, which cost our forefathers such enormous labour.

The supply and distribution of water in a large city, particularly since the steam-engine was added to the apparatus, approaches closely to the perfection of nature's own work in the circulation of blood through the animal body. From the great pumps or a high reservoir, a few main pipes issue to the chief divisions of the town; these send suitable branches to every street, the branches again divide for the lanes and alleys; and at last into every house a small leaden conduit rises, which, if required, carries its precious freight into the separate apartments, and yields it there to the turning of a cock. A corresponding arrangement of drains and sewers, constructed with the greatest exactness in obedience to the law of level, receives the water again when it has answered its purposes, and carries it to be purified in the great laboratory of the ocean. And so admirably complete and perfect is this counter-system of sloping channels, that a heavy shower may fall, and after washing and purifying every superficial spot of the city, and sweeping completely all the subterranean passages, within the space of an hour, it may be again collected in the river passing by. It is the recurrence of this almost miracle, of extensive, sudden, and perfect purification, which has made London the most healthy, although the largest city in the world.

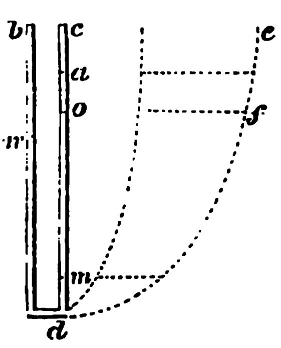
English citizens have now become so habituated to the blessing of a supply of pure water more than sufficient for all their purposes, that it no more surprises them than the regularly returning light of day or warmth of summer. But a retrospect into past times may still awaken them to a sense of their obligation to advancing art. How often, formerly, did periodical pestilence arise from deficiency of water; and often has fire devoured whole cities, which a timely supply of water might have saved. Kings have received almost divine honours for constructing aqueducts, to lead the pure streams from the mountains into the peopled towns. In the present day, only he who has travelled on the sandy plains of Asia or Africa, where a well is more prized than mines of gold, or who has spent months on ship-board, where the fresh water is often doled out with more caution than the most precious product of the still, or who has vividly sympathized with the ship-wrecked man spreading out his garments to catch the rain from heaven, and then, with mad eagerness, sucking the delicious moisture—only he can appreciate fully the blessing of that abundant supply which most of us now so thoughtlessly enjoy. The author will long remember the intense momentary regret with which, on once approaching a beautiful land after months spent at sea, he saw a stream of fresh water falling over a rock into the salt waves—it appeared to him, that he was witnessing a most precious essence, by some accident, pouring out to waste.

The subject of *fluid level* leads to the consideration of springs or wells, and of the operation of boring for water.

The water which falls from the clouds may either find its way directly to the rivers, by running along the surface of a soil that refuses it admittance; or may sink into the porous earth, and again ooze out at some lower situation in the form of a spring. If a spring be as low as the bottom of the porous earth from which it issues, that is to say, as low as the surface of the impermeable clay or rock on which the earth rests, it may drain the whole; but if not, the water will stand at a certain level among the earth as it would among bullets in a pit. If a hole or pit be then dug in such earth, to below the level of the water lying in it, the pit will soon be filled with water up to such level, and will be called a well. In many places the level of the subterranean water is very low, and in some, by reason of the water having an easy drainage towards the sea, or of the soil being altogether impermeable to it, there is no water within an accessible depth.

The surface of our globe is formed of different strata or layers, as of clay, chalk, sand, gravel, &c. &c., which appear all to have been at some former period horizontal, and under water, and to have been afterwards thrown up, by some convulsion of nature, in every variety of state. In particular situations the upper surface is concave, or basin-shaped, and then the different strata or layers, when water-tight, are like cups or basins placed one within another; and as water poured in between two basins so placed, until it reached their lips, would spring out to the height of its source, by any hole made through the side of either, so on boring for water through an innermost water-tight stratum or basin of earth, the water often springs out and rises far above the surface. London stands in a hollow of which the first or innermost layer is a basin of clay, placed over chalk, and on boring through the clay (sometimes of three hundred feet thickness,) the water issues, and in many places rises considerably above the surface of the ground; showing that there is a higher source or level somewhere—probably among the Surrey hills, or those north of London.

When fluids of different kinds, and of different weights under the same bulk, are made to act against, or to balance each other in communicating vessels—as water, for instance, in one leg of the bent tube *b d c*, and oil in the other—the surfaces will not be at the same height or level, but that of the lighter fluid will be just as much higher than that of the other as it is lighter. Thus the column of oil must be of a length as *o d*, to balance the column of water *w d:* and alcohol, because lighter than oil, to balance the same water, would have to stand higher still as at *a:* while mer-

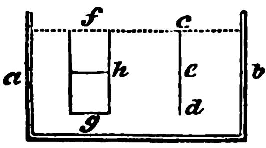


cury, because thirteen times weightier than water, would stand only about *m*. The shape, size, or position of the vessels in which the opposing fluids might stand, would have no influence on the relative height of the surfaces; and if we suppose a larger vessel, such as is represented by the dotted lines here, to replace the leg *c d* of the tube, the various fluids to balance the water in *b d*, would have to stand just as high in it, as in the smaller tube *c d*.

" *A body immersed in a fluid, displaces exactly its own bulk of it, which quantity having been just supported by the fluid around, the body is held up with force exactly equal to the weight of the fluid displaced, and must sink or swim according as its own weight is greater or less than this.*"

A bladder full of air, and maintaining the bulk of a pound of water, requires a force of one pound (except a grain or two, the weight of the air) to plunge it under water. The same bulk of gold is held up in water with exactly the same force, and if previously balanced at the end of a weighing beam, it appears on immersion to have lost one pound of its weight. And a piece of wood, ivory, or any other substance, provided it has exactly the same bulk, is opposed on entering the fluid by the same resistance.

The reason of this is obvious, for the immersed body takes the place of water, which weighed one pound and yet was supported. In a vessel of water represented here by *a b*, let us attend to any portion of the water, a single column of particles for instance, represented by the line *c d:* we know that each column is steadily supported in its place, because the particle of the liquid immediately under it is tending upwards to escape from the surrounding pressures, with force exactly equal to its weight; and what is true of a column of single particles, is true of any other portion, such as the larger column represented by the figure *f h g*. If such portion weighed ex-



actly a pound, the surface under it would be tending upwards with the force of a pound; and if the portion, without changing its bulk or form, were to become ice, it would still be exactly supported by the surface below pressing upwards with force of a pound; and further, if such a column of wood, stone, or metal were there, the surrounding pressures would still be the same. Again, if we suppose only half the column to be solidified, the portion *h g* for instance, it would still be pressed upwards with a force of one pound at *g;* but its own weight of half a pound, and the weight of the half pound of water above it, would produce an exact balance and maintain rest.

It is very important to have clear notions on this subject; and as different minds apprehend with different degrees of facility, and in different ways, I shall state the same general truth in other words.

Let us regard a mass of fluid, as consisting of a vast number of extremely minute columns of single particles standing side by side, where every particle supports those above it by the tendency upwards which it acquires through the pressure of the fluid surrounding it. Now if we suppose the particles of a portion of the fluid mass, of any shape, to stick together or to become ice without change of bulk or weight, that portion when solid would still be between the same forces as when fluid, and therefore would be equally supported, and would remain at rest. And if gold, or silver, or glass, or wood, having the same bulk, were substituted for the supposed ice, such new substance would still be sustained with the same force; so that if it were of exactly the same weight as the ice or water displaced, it would have no tendency either to rise or to fall, more than the water itself had; but if it were heavier it would sink, and if lighter it would swim, and in either case with force exactly proportioned to the difference between its weight and that of an equal bulk of water.

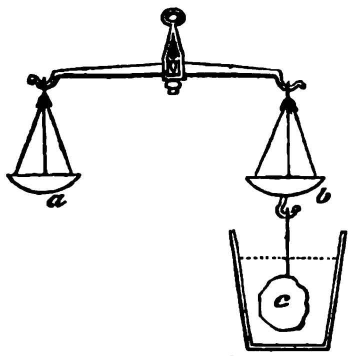
Few persons, in reading for the first time the statement of this simple truth, and which now appears so obvious, would imagine that it had been so long unknown, and that it is one of the most important discoveries which human sagacity has ever made,—but so it is. We owe the discovery to the master-mind of antiquity—that of Archimedes, who caught the idea one day while his limbs were resting on the liquid support of a bath: and as his godlike intellect darted into futurity, and perceived many of the important uses to which the knowledge was applicable, he is said to have become so moved with admiration and delight, that he leapt from the water, and, unconscious of his nakedness, pursued his way homewards, calling out "ευρηκα ευρηκα," I have found it. He was thinking chiefly of the ready means, thus obtained, of ascertaining in all cases what has since been called the *specific gravity* of bodies, *viz.* the exact comparative weights of the same bulk of different substances; as of gold compared with silver, or copper, or iron, &c.; and in the case of mixtures, as of gold with silver for instance, of declaring at once the proportion present of each—important problems which, until then, no one could correctly solve.

The hydrostatic law now explained, has since led to great advances in various arts. It may be regarded as a chief foundation of chemistry, for by it the chemist distinguishes one substance from another, a pure substance from an impure one, and the nature of mixtures or compounds. The merchant often judges by it of the worth of his merchandize. In any case it enables an inquirer to ascertain at once the exact size or solid bulk of a mass, however irregular. It has become the cause of improvements in navigation, in marine architecture, &c. &c.

We shall now discuss more particularly the subject of *comparative weights* or *specific gravities.*

> "*The force with which a body is held up in a fluid being the exact weight of its bulk of that fluid, by ascertaining this force and comparing it with the weight of the body itself, the comparative weights* or SPECIFIC GRAVITIES *are found.*" (*Read the analysis, page* 236.)

If any body, *c*, a mass of gold for instance, be suspended by a thread or hair from the bottom of one scale *b* of a weighing beam, and be then balanced by weights put into the other scale *a*, and if a vessel of water be then lifted under it so that the water shall surround it, the body is pushed up or supported by the water with force equal to the weight of the water which it displaces; the weight, therefore, then required in the scale *b* to restore the balance, is truly the exact weight of the water displaced; or of water equal in bulk to the body; and the weights in the two opposite scales show the comparative weights of a given bulk of the body and of water. Suppose the piece of gold in the present case to have some certain weight in the air, it would seem to lose, when the water surrounded it, about a nineteeth part of its weight; that is, the water would support it with this force; and gold would thus be proved to be about nineteen times as heavy as water.



In making a table of specific gravities, it was necessary to select a common standard with which all other substance should be compared, and this has been done in choosing water; the reasons of preference being, that water can be so easily procured in a state of purity, and therefore of uniformity, in all situations. When we say, therefore, that gold is of the specific gravity 19, and copper 10, and cork ¼, we mean that these substances are just so much heavier or lighter than their bulk of pure water in its densest state, *viz.* at the temperature of 40 degrees of Fahrenheit's thermometer.

As the substances in nature are various as to form and other qualities, corresponding differences have to be made in the manner of ascertaining their specific gravities: the following are the most important.

Solid bodies insoluble in water and heavier than it, as the metals, &c., are merely suspended by a thread or hair having nearly the specific gravity of water, to one scale of the *hydrostatic balance* (which is simply a good weighing beam with a water-vessel below it;) and the body being first balanced or weighed in the air, and then in water as already described, the weight and the loss, represented by the weights in the opposite scales, are the weights of equal bulks of the two substances; and by finding, through the arithmetical operation of *division*, how often the weight of the water is contained in the weight of the solid, we find the specific gravity of the solid, or how much it is weightier than its bulk of water.—It is almost superfluous to remark, that putting weights into the scale *b*, or taking them out of the scale *a*, are equivalent operations.

Solids lighter than water, as cork, are weighed in it, by attaching to them a mass of metal or glass, already balanced in water for the purpose, which may cause them to sink; or by making the line which connects them with the weighing beam pass under a small pulley fixed at the bottom of the vessel, so that the rising of the end of the beam shall draw them down.

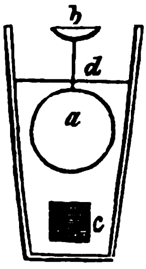
A solid soluble in water, as a crystal of any salt, may be protected during the operation, either by previously dipping it in melted wax, so as to leave a thin covering on it, or it may be weighed in some liquid which does not dissolve it, allowance being afterwards made for the difference between the weight of such liquid and of water.

Powders insoluble in water, such as gold-dust, are weighed in a glass cup, which has been previously balanced in water for the purpose.

Powders soluble in water must be weighed in some other liquid.—Mr. Leslie, the highly endowed professor of natural philosophy in the university of Edinburgh, has lately suggested a novel and ingenious mode of ascertaining the specific gravities of pulverized or porous bodies; but as it can be understood only by persons acquainted with the doctrines of *pneumatics*, the consideration of it must come under that head.

Other liquids may be compared with water, in several ways.

1st. If a phial be made to hold exactly one thousand grains of water, the weight of the same measure of any other liquid is found, by simply filling the phial and weighing it. Of sulphuric acid, for instance, such a phial will contain nearly nineteen hundred grains, while of alcohol it will receive only about eight hundred. 2d. A bulb of glass, which loses one thousand grains when weighed in water (which thousand grains is therefore the weight of its bulk of water,) may be weighed in other liquids, and the difference of loss marks the specific gravity, as in the last case. The bulb may be of any size, but one which loses in water, exactly one thousand grains, is preferable, from the simplicity thereby given to the calculations. This remark applies also to the phial last mentioned. 3d. A contrivance which renders the beam and scales altogether unnecessary, is a hollow bulb of glass or metal *a*, with a slender stalk rising from it, to support the little scale or dish *b*, and with another stalk descending to carry the weight or weights at *c*, which serve as ballast to it when floating. The whole is so adjusted as to float in pure water, with a certain mark upon the upper stalk, at the surface of the water. By then immersing it in other liquids, and by finding how much weight must be added to or taken from it above or below, to make it float in them at the same elevation, the comparative weights of these other liquids and of water are found:—or the difference of weight which makes it float at different elevations having been previously ascertained, it will only be necessary to note exactly its elevation. This instrument is called an *hydrometer*. There are generally printed tables and directions accompanying all forms of it, telling the exact import of the several indications for different liquids, and the allowances required to be made for temperature, &c. 4th. The shortest mode of ascertaining the specific gravities of liquids, is to have small glass bubbles, forming a set or series of different specific gravities, so that when thrown into any liquid, those heavier than it will sink, and those lighter will swim, and that one which marks its specific gravity will just remain suspended. The individuals of the series must of course be numbered, and the specific gravity of each known.



The common use of hydrometers is to ascertain the quality of the distilled spirits brought to market, as rum, brandy, gin,

&c. All these consist of alcohol more or less diluted with water; and duty or tax is levied upon them in proportion to the strength, or the quantity of alcohol which they contain. A delicate hydrometer discovers this at once.

A shopkeeper in China sold to the purser of a ship, a quantity of distilled spirit according to a sample shown; but, not standing in awe of conscience, he afterwards, in the privacy of his store-house, added a certain quantity of water to each cask. The spirit having been delivered on board, and tried by the hydrometer, was discovered to be wanting in strength. When the vender was charged with the intended fraud, he at first denied it, for he knew of no human means which could have made the discovery; but on the exact quantity of water which had been mixed being specified, a superstitious dread seized him, and he confessed his roguery, and made ample amends. On the instrument of his detection being afterwards shown to him, he offered any price for what he foresaw might be turned to great account in his trade.

The specific gravity of an *aeriform substance* is ascertained by means of a glass flask of known size, furnished with a stopcock. It is first weighed when emptied by the air-pump, and afterwards when filled successively with water and with the different airs or gases. Comparison of the weights gives the specific gravities as already described.

The following table shows in round numbers the comparative weights or specific gravities of some common substances. Water is the standard kept in view, and any equal bulk of the other substances is heavier or lighter than water, according to the numbers severally attached to them.

Platinum	22½	Common Salt	2
Gold	19⅓	Brick	2
Mercury	13½	Alcohol	$\frac{8}{10}$
Copper	8¾	Æther	¾
Steel and Iron	8	Cork	¼
Diamond	3½	Atmospheric Air	$\frac{1}{800}$
Glass	3	Hyrogen Gas	$\frac{1}{12000}$
Common Stones	2½		

Complete tables are found in systems or Dictionaries of Chemistry.

A cubic foot of water happens to weigh one thousand ounces avoirdupois. Hence in the foregoing table the figures denoting the specific gravities, tell how many thousand ounces of the different substances a cubic foot contains. Of gold, for instance, a cubic foot contains more than nineteen thousand ounces, and is worth about £63,000 in money. A cubic foot of common air contains only a little more than one ounce; and of hydrogen gas, the lightest of ponderable things, it contains less than a drachm.

The following facts are also illustrations of the truth, that a body immersed in a fluid is held up or resisted with force equal to the weight of the quantity of fluid which it diplaces.

A stone which on land requires the strength of two men to lift it; may be lifted and carried in water by one man. There are cases, therefore, where the support of water obtained in this way is equivalent to the assistance of an additional hand. A boy will often wonder why he can lift a certain stone to the surface of water, but no farther.

The invention of the diving-bell in modern times, having enabled men in the building of piers, bridges, &c. to work under water almost as freely as above its surface, many have experience of this influence of water: but workmen are generally surprised at first, to find that they can move much larger and heavier stones down below than in the air. Some have supposed the fact accounted for by saying that the denser air of the diving-bell when received into the lungs gave greater strength. In recovering property from a sunken ship by the diving-bell, every thing is found to be lighter in the proportion just stated.

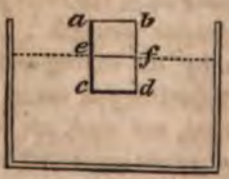
This law explains also why stones, gravel, and sand, are so easily moved by waves and currents. Many people expressed astonishment, in March 1825, on learning that at the Plymouth Break-water, the storm had displaced blocks of stone, of many tons weight; but we now see that the moving water had only to overcome about half the weight of the stone.

When a person lies in a bath, the limbs are so nearly supported by the water as to require scarcely any exertion on the part of the individual. This softest of all beds being indulged in for half an hour or more, the person on first lifting a limb out of the water, feels surprise at its great apparent weight. The workers about diving-bells always experience the sensation now spoken of, on returning to the air.

The bodies of most fishes are nearly of the specific gravity of water, and therefore, if inactive, they neither sink nor rise very quickly. When this subject was less understood, many persons believed that fishes had no weight in water; and it is related as a joke at the expense of philosophers, that a king having once proposed as a question to his men of science, to explain this extraordinary fact, many profound disquisitions came forth, but not one of the competitors thought of trying what really was the fact. At last a simple man balanced a vessel of water in scales, and on putting a fish into it, showed a scale preponderating just as much as if the fish had been weighed alone.

In the sense now explained, water is said to have no weight in water. The least force will raise a bucket of water from the bottom of a well to the surface; but if the bucket be lifted at all farther, its weight is felt, just in proportion to the part of it which is above the surface.

"A body lighter than its bulk of water will float, and with force proportioned to the difference." (*Read the analysis, p.* 236.)



The reason of this is clear. If any body, the cylinder *a, b, c, d*, for instance, be partially immersed in water, we know that the upward pressure of the water on the bottom of *c d*, is exactly what would support the water displaced by the body, *viz.* water of the bulk, *e f c d*. The body therefore, that it may remain in the position here represented, or that it may float, must have exactly the weight of the water which it displaces; and if it be lighter than this, it will rise further; if heavier, it will sink further.—A body when floating in water, then, is pushed up until just so much of it remains in the water as to occupy the place of a quantity of water equal in weight to itself.

Hence a pound weight of any body which floats in water, displaces just a pound of water, whether that body be very light, as cork, or heavier, as a piece of dense wood. This is experimentally shown by putting such bodies to float in a vessel originally full of water. The water displaced by each must run over the sides of the vessel, and may be caught and measured.

Hence, a porcelain basin of four ounces will sink in water only as far as a similar wooden bowl of the same weight; and the weight of the bowl may either be in the wood itself, or in any thing else put into it as a load.

Hence a boat of iron floats just as high out of water as a similar boat of wood, if that of iron be thinner in substance, and therefore not heavier, upon the whole, than the wood. An empty metallic pot or kettle is often seen floating with a great part of it above the surface of the water.—Prejudice for a long time prevented iron boats from being used, although they are superior to others for various purposes: and there are many people still who would fear to go on board of a ship built of the strong and almost everlasting Indian teak, because it is heavier than water, and in the form of a log, therefore, sinks in water. Many fine ships of the line, however, and East-Indiamen of fifteen hundred tons or more, are now built of teak.

Hence a ship of one thousand tons will just draw as much water, or float to the same depth, whatever her cargo be, if of equal weight.—And the exact weight of a ship and her cargo would be determined by finding how much water she displaced. In canal boats, which are generally of a simple form, this truth affords a ready rule for ascertaining the quantity of their load.

The human body, in an ordinary healthy state with the chest full of air, is lighter than water.

If this truth were generally and familiarly understood, it would lead to the saving of more lives, in cases of shipwreck and in other accidents, than all the mechanical life-preservers which man's ingenuity will ever contrive.

The human body with the chest full of air is so much lighter than water, that it naturally floats with a bulk of about half the head above the water,—having no more tendency to sink than a log of fir. That the person may live and breathe, then: it is only necessary to exert volition so as to render the face the part which remains uppermost.

The reasons that so many people are drowned in ordinary cases, who might easily be saved, are the following:—

1st. Their believing that continued exertion is necessary to keep the body from sinking, and hence their generally assuming the position of a swimmer, in which the face is downwards, and the whole head must be kept out of the water to allow of breathing. Now as a man cannot retain this position without continued exertion, he is soon exhausted, even if a swimmer, and if not, the unskilful attempt will scarcely secure for him even a few respirations. The body raised for a moment by exertion above the natural level, sinks as far below when the exertion ceases; and the plunge, by appearing the commencement of a permanent sinking, terrifies the unpractised individual, and renders him an easier victim to his fate.

2d. From a fear that water entering by the ears may drown, as if it entered by the nose or mouth, a wasteful exertion is made to prevent it; the truth being, however, that it can only fill the outer ear, or as far as the membrane of the drum, and is therefore of no consequence. Every diver and swimmer has his ears filled with water, and with impunity.

3d. Persons unaccustomed to the water, and in danger of being drowned, generally attempt in their struggle to keep their hands above the surface, from feeling as if their hands were tied while held below; but this act is most hurtful, because any part of the body kept out of the water, in addition to the face which must be so, requires an effort to support it which the individual is supposed at the time incompetent to afford.

4th. Not having reflected, that when a log of wood or a human body is floating upright, with only a small portion above the surface, in rough water, as at sea, every wave in passing must cover the head for a little time, but will again leave it projecting in the interval. The practised swimmer chooses this interval for breathing.

5th. Not knowing the importance of keeping the chest as full of air as possible; the doing which has nearly the same effect as tying a bladder of air to the neck, and without other effort will cause nearly the whole head to remain above the water. If the chest be once emptied, and if from the face being under water the person cannot inhale again, the body is then specifically heavier than water, and will sink.

When a man dives far, the pressure of deep water compresses, or diminishes the bulk of the air in his chest, and hence he becomes really heavier than water, and would not again rise, but for the exertion of swimming. The author once saw a sailor (a fine-bodied West-Indian negro) fall into the calm sea from a yard arm eighty feet high. The velocity was so great, that he shot deep into the water immediately, and, of course, his chest was compressed as now explained: probably also the shock stunned him, for although he was an excellent swimmer, he only moved his arms feebly once or twice, and was then seen gradually sinking for a long time afterwards, until he disappeared, as a black and distant speck, towards the unknown regions of the abyss.

It is not to be expected that every person should learn to swim; but every one who makes voyages, should have practised the easy lesson of resting in the water with the face out. The head, from the large quantity of bone in it, is a heavy part of the body, yet a little action of adjustment with the hands easily keeps it uppermost; and there is an accompanying motion of the feet, called *treading the water*, not difficult to learn, which sustains the entire head above the surface. Perhaps the whole of the seventy passengers who were swallowed up on the sudden sinking of the Comet steam-boat near Greenock, in November 1825, might have been saved in the boats which so soon went to their assistance, had they known the truth which we are now explaining.

In having to swim far, a man may rest on his back for a time, and resume his labour when he is somewhat refreshed.

So little is required to keep a man's whole head above water, that many individuals, altogether unacquainted with what regards swimming or floating, have been saved after shipwreck, by catching hold of a few floating chips or broken pieces of wood. An oar will suffice as a support to half a dozen people, if no one of the number attempts to keep more than his head out of the water; but from each wishing to have a good share of the security it is often rendered less useful than it might be.

A common life-preserver consists of strings of corks put round the chest or neck; or of an air-tight bag applied round the upper part of the body, and which can be filled by the person blowing into it through a valved pipe.

On the great rivers of China, where thousands of people find it more convenient to live in covered boats upon the water, than in houses on the shore, the younger male children have a hollow ball of some light material attached constantly to their necks, so that in their frequent falls overboard, they are not in danger.

Life-boats have a large quantity of cork mixed in their structure; or of air-tight vessels of thin copper or tin plate, so that even when the boats are filled with water, a considerable part still floats above the general surface.

Swimming is much easier to quadrupeds than to man, because the common motion of their legs in walking and running is that which best supports them in swimming. Man is the most helpless of creatures in water. A horse can carry his rider with half the body out of the water; dogs that have never been in water before, swim well on the first trial. Swans, geese, and water-fowls in general, are so bulky and light, by the great thickness of feathers under them, that they float upon the water like stately ships, moved by their webbed feet as oars.

A man in deep water may walk upon broken glass with impunity, because his weight is supported by the water.

But many men have been drowned in attempting to wade across the fords of rivers, from forgetting that the body is supported by the water, and does not press on the bottom sufficiently to give a sure footing against a very trifling current. A man therefore, carrying a weight on his head or shoulders, may safely pass a river, where without a load, he would be carried down in the stream.

There is a mode of catching wild ducks, practised in China, which requires that the catcher be well loaded or ballasted. Light grain being first strewed upon the surface of the water to tempt them, a man hides himself in the midst of it, under what appears a gourd or basket drifting with the stream, and when the flock approaches and surrounds him, he quickly obtains a rich booty by snatching the creatures down one by one—making them appear as if they were diving, and then securing them below. Each bird becomes as a piece of cork attached to his body.

Fishes can change their specific gravity, by diminishing or increasing the size of a little air-bag contained in their body. It is because this bag is situated towards the under side, that a dead fish floats with the belly uppermost.

Animal bodies, in undergoing the process of putrefaction, give out much aeriform substance. Hence the bodies of drowned persons generally swell after a time, and rise to the surface, again to sink when the still increasing quantity of air shall burst the containing parts.

A body floats to the same depth whether the mass of fluid supporting it be great or small:—a porcelain basin for instance, whether placed in a pond, or in another basin, so little larger than itself, that a spoonful or two of water suffices to fill up the interval between them. One ounce of water in this way may float a thing of a pound weight, exhibiting another instance of the *hydrostatic paradox:* and if the largest ship of war, ready for sea, were received into a dock, or case, so exactly fitting her that there were only half an inch of interval between her and the wall around, she would float as completely when the few hogsheads of water required to fill this little interval up to her usual water-mark were poured in, as if she were on the high sea. In some canal locks, the boats just fill the space in which they have to rise and fall, and thus the expense of water at the lock is diminished.

A floating body, to be stable in its position, must either have its centre of gravity below the centre of gravity of the fluid which it displaces—called the *centre of buoyancy*, or it must have a broad bearing on the water, so that any inclination may cause the centre of gravity to ascend.

Hence arises, in the stowing of a ship's cargo, the necessity of putting the heavy merchandize underneath, and generally of putting iron ballast under all the merchandize. Hence, also, the danger of having a cargo or ballast which is liable to shift its place. A ship loaded entirely with stones, is sometimes lost, by a wave making her incline for a moment so much that the load shifts to one side, which is then kept down. For a similar reason, a cargo of salt or sugar has a certain danger attached to it, for if the ship leak, the cargo may be dissolved, and then pumped out with the bilge water, altering her trim. In a fleet coming home from India in 1809, four fine ships were lost in a hurricane off the Isle of France, and from what happened to the others ships that were saved, the cause was supposed to be, that the salt-petre of the cargoes had been dissolved and pumped out, and that the ships in consequence became unmanageable.

Bladders used by beginners in swimming are dangerous, unless secured so as not to shift towards the lower part of the body.

A great inventor (in his own estimation) published to the world, that he had solved the important problem of walking safely upon the water; and he invited a crowd to witness his first essay. He stepped boldly upon the wave, equipped in a pair of bulky cork boots, which he had previously tried in a butt of water at home: but it soon appeared that he had not pondered sufficiently on the centres of gravity and of flotation, for in the next instant all that was to be seen of him was a pair of legs sticking out of the water. He was picked up by help at hand.

and with his genius cooled and schooled by the event, was conducted home.—Some soldiers once finding a few cork *jackets* among old military stores, determined to try them; but mistaking the shoulder straps for lower fastenings, they put them on as *drawers*, and on then plunging in, with the hope of being able to sit pleasantly on the water, their heavy heads went down, and they were nearly drowned.

When, on the return of summer, the ice breaks up in the polar regions, immense islands are set afloat, rising high into the air and sinking deep into the sea. The melting process, in most cases, does not go on equally in the water and in the air, and from the mass consequently changing form, its stability is often lost, and one of the grandest phenomena in nature follows—the overturning of a mountain—the sudden subversion of an island—producing a tumult in the ocean around, felt often at the distance of many leagues.

The phenomena of pressure, floating, &c. in fluids, vary in exact proportion to the weight or specific gravity of the fluid.

A ship draws less water, or swims lighter, by one thirty-fifth, in the heavy salt water of the sea than in the fresh water of a river; and for the same reason a man supports himself in swimming more easily in the sea than in a river.

Many kinds of wood that float in water will sink in oil.

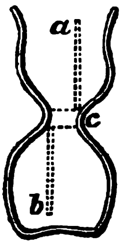
A man floats on mercury as the lightest cork does on water, and with practice he might be able to walk upon mercury.

Had the water of our ocean been but a little heavier than it is, men after shipwreck might have died of famine and cold, but would not have been drowned.

Oil floats on water, but sinks in alcohol or ether. The term *proof spirit* means spirit light enough for oil to sink in it. The strength of spirit is proportioned to its lightness.

Cream rises in milk, and forms a covering to it.

Blood, allowed to rest after flowing from the living body, separates into parts, which arrange themselves according to their specific gravities. The buffy coat of inflammation (where this exists) is uppermost; then comes the general coagulum: at the lower part of this there is an accumulation of red globules; and the whole of the coagulum or crassamentum floats in the serum, which is therefore lowest of all. When the red globules escape from the coagulum they fall to the bottom even of the serum.



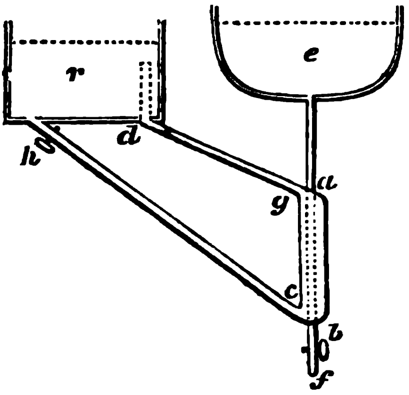
Wine if slowly and carefully poured on water, will float upon it. In a vessel shaped like a common sand-glass, but having a larger opening between the chambers at *c*, if wine be put into the under chamber, and water into the upper, the two liquids will change places: and if the lower half of the glass be covered, so as to leave the upper half with the appearance of a simple goblet, the water will seem to have been changed into wine. The liquids are less mixed, and change places sooner, when there is a tube *b* to carry the water down to the bottom before touching the wine, and a tube *a* to carry the wine directly to the top.

Mercury, water, oil, air, and some other fluids may all be shaken together in the same vessel, and on standing will separate and arrange themselves in the order of their specific gravities.

When in a mass of water, part of it is heated more than the rest, that part, by its expansion, becomes specifically lighter than the rest, and then rises to the surface. Hence, when heat is applied to the bottom of a vessel containing water, there is a circulation established, which goes on from the first moment until the operation of heating finishes:—water is always rising from the hotter parts of the vessel, and descending over the colder parts.

In like manner, when a tall glass of hot water is dipped into cold water, a downward current takes place within the glass near the sides all round, and there is an upward current in the middle. The motion is rendered very obvious by small portions of amber thrown into the water, for these being nearly of the specific gravity of water, rise and descend with it. On account of the current established in such cases, heat applied to the bottom of a vessel of liquid is soon equally diffused over it; but heat applied at the top is there confined, because the heated and lighter fluid does not descend. Water may be made to boil at the surface, while a piece of ice lies at the bottom. The converse is impossible.

The current in a fluid, produced by local change of temperature, is an important part of the following process, which the author deems applicable to various useful purposes.—Heat may be transferred from one liquid to another, without mixing them by making the hot liquid descend in a very thin metallic tube, through the cold liquid rising around it in a larger tube. Boiling water from the vessel *e*, for instance, may descend slowly by the small tube *e a b f*, which is surrounded from *a* to *b* by cold water ascending through the tube *c g*. Then as the temperature of two liquids which are brought so nearly in contact with each other, will not, after a very short time differ in any one place more than a few degrees, it follows that the water lately cold, will on leaving the part of the tube *g*, which is in contact with the boiling water descending directly from *e*, be nearly boiling, while the water lately hot, will on leaving the tube at *b*, which is in contact with cold water just arrived from *h*, be itself nearly cold: and thus equal quantities of hot and cold water will have exchanged temperatures. The flux of the hot water is to be regulated by a cock *b*, and that of the cold water by a cock *h*. The water in the part of the tube *c g d* rises, because it is hotter and lighter than that in the part *h c*.—The author believes that an apparatus made on this principle, with an arrangement of many thin flat tubes instead of a single large tube, for the descending fluid, and a spacious box *c g* to contain these and the rising fluid, would be an excellent refrigerator in



a distilling apparatus, and for cooling the wort of brewers; or would serve as a means of diminishing the expense of warm baths, by transferring the heat from the water lately used, to pure water. In distilling the *wash* or *low wines* about to enter the still, might be used as the cold condensing fluid to surround the worm or vapour-tubes, and thus, without expense, would be heated in its progress to the still. Half the original expense of a great porter brewery is in the construction of the numerous water-tight floors on which the hot wort is thinly spread to cool.—And the practise of warm bathing, so conducive to health, is less common in this country, because the present expense is so great.

It is a general truth in nature, that substances contract in size as they cool. There is, however, in water, a curious exception to this rule, which, operating through the principle of specific gravities, effects most important purposes in the economy of nature. Water contracts only down to the temperature of forty degrees, below which, towards thirty-two degrees, or the freezing point, it goes on dilating again, and as ice is much lighter than as a fluid. Ice therefore floats on the surface of water, and being a very bad conductor of heat, defends the water underneath from the cold air, preserving it liquid, and a fit dwelling for the finny tribes, until the return of the mild season. Not only is the extreme of cold below thus prevented, but because water becomes more bulky in proportion as its temperature falls under forty degrees, very cold water remains floating on the surface of a wintry lake, as cream floats on milk, and preserves underneath that warmth which is agreeable to the fishes, just as very hot water in summer remains uppermost, preserving underneath an agreeable coolness. By the formation then of ice and snow, nature has prepared a winter garb for the inhabited lakes and rivers, as complete and effectual as she has for the terrestrial animals, by the periodical thickening of their wool or fur. Had ice become heavier than water, so that it must have fallen to the bottom, and have left the surface without protection, a deep lake would have been frozen, in European winters, into a solid lifeless mass, which summer suns would no more have melted than they now do the glaciers of Switzerland. But for this important exception, therefore, to a general law of nature, many of the now most fertile and lovely portions of the earth's surface would have remained for ever barren and uninhabited wastes.

PART III.

DOCTRINE OF FLUIDS.

SECTION II.—PNEUMATICS.

ANALYSIS OF THE SECTION.

In aeriform fluids, that is, in such as have their particles held far apart by a mutual repulsion, which yields, however, to any force applied, so that the mass suffers great change of volume under different degrees of compression,—the phenomena will be modified by their GREAT LIGHTNESS *and* ELASTICITY, *but will still be in strict accordance with the general properties of fluids already explained, viz.* PRESSURE EQUAL IN ALL DIRECTIONS—PRESSURE AS THE DEPTH—LEVEL SURFACE, *and* FLUID SUPPORT. *The pressure of air, in all directions, and as the depth may be studied in the effects of our atmosphere*—on solids—on liquids: —*or when it concurs with heat, in producing the phenomena of* boiling, evaporation, clouds, rain, dew, &c. *or when, by varying in degree, it allows certain substances to exist sometimes in the* liquid *and sometimes in the* aeriform *states. The fluid support in air is exemplified by* balloons, *the* ascent of flame *and* smoke, winds, *&c.*

What a change has taken place in the degree of man's knowledge of nature, since philosophers thought that air was one of four primary elements, viz. *air*, *fire*, *water*, and *earth*, of which all things were composed, and each of which was for ever distinct from the others. We now know that air or gas is merely an accidental state, in which any body may exist, according to the quantity of heat pervading it: the body being solid when the absence of heat allows its atoms to obey freely their mutual attraction, and to cohere—as in ice, for instance; being liquid, when so much heat is present as to separate them and let them slide freely among each other—as they do in water; and being aeriform when still more heat is added, causing the atoms mutually to repel and dart asunder to a great distance—as they do in steam. But in any one of these three states, the various substances are as much themselves as in the others, and at the command of the chemist will assume any of the forms which he desires. As most substances in nature have a different relation to heat, there are some in the variety which at the medium temperature of our earth are solid, some which are liquid, and some aeriform. The solids, in general, are the heaviest under a given volume, and therefore sink down and form the great mass or centre of the earth; the liquids follow next in order, and float upon this solid centre, filling up its inequalities with a level surface, so as to constitute the ocean; while the airs are the lightest of all, and as a second ocean, rest above the sea and above the highest mountains to an elevation of about fifty miles. There are two substances, in particular, of which it is the nature, when not restrained in certain combinations, to assume the form of air at very low temperatures, viz. *oxygen* and *nitrogen*, and of these, therefore, the atmosphere chiefly consists; but smaller portions of almost every other substance are found in it. Water, among the supplementary matters, is much more abundant than any of the others, and in its various states of cloud, mist, rain, dew, and snow, it answers a thousand useful purposes, and serves beautifully to vary the scenes of nature. The atmosphere is about fifty miles high or deep, and therefore, in relation to the bulk of the earth, is as a covering of one-tenth of an inch in thickness to a common library globe of a foot in diameter.

The atmospheric ocean is the great laboratory in which most of the actions of life go on, and on the composition of which they depend. A human being requires for breathing, a gallon of fresh air every minute, dying equally if deprived of it, or if confined to the same. All other animals also require fresh air but in various proportions. And in the vegetable creation, the beautiful green leaf and delicate flower are merely broad and tender expansions of surface for the contact of the vivifying air. Animals give out to the atmosphere a substance which vegetables absorb, and vegetables, by the absorption, fit the air again for the use of animals; so that, upon the whole, in the various changes of nature, there is a perfect balancing of actions preserving the atmospheric mass in a uniform state, constantly fit for its admirable purposes.

While the ancients had that notion of air, which made them apply to it vaguely, and almost indifferently, the names of *air*, *ether*, *spirit*, *breath*, *life*, &c., they never dreamed of making experiments upon it, with a view to prove its relation to common matter:—and one of the most beautiful portions of the history of man's progress in knowledge, is that which exhibits the light gradually breaking in, in modern times, upon this most interesting subject. Galileo discovered that air made a definite pressure upon things at the surface of the earth; Torricelli and Pascal proved that this was occasioned by its weight, and they measured the height of the aerial ocean; Priestly, Black, Lavoisier, and others, dicovered that air might be united to a metal, so as to increase its weight, and to produce a compound of totally new qualities; and they showed that many of the ores of our mines are merely metals concealed, by being thus united with a substance, which when set free ascends as one of the ingredients of the atmosphere. They at last analyzed the atmosphere itself, and exhibited its ingredients as distinct substances, having each peculiar properties. Within a few years the true nature of air or gas has been thoroughly investigated. We can now take a little of that most light, invisible, impalpable fluid which we breathe, and squeezing the heat out of it by strong pressure, we can make its particles collapse from their aeriform distances to assume the state of a tranquil oily fluid; which may then be retained as such for ever, or may be decomposed and made solid in combination with other bodies, or may be again set at liberty.

The suspicion once excited, that air was as much a material fluid as water, only much less dense, by reason of a greater separation and repulsion of the particles, it was easy to follow out the parallel, and to confirm the supposition by reference to the commonest facts. The motion of a flat board is resisted in water: the motion of a fan is resisted in the air. Masses of wood, sand, and pebbles, are rolled along or floated by currents of water: chaff, feathers and even rooted trees, are swept away by currents of air. There are mills driven by water: and there are mills driven by the wind. Oil set free under the surface of water, or placed there in a bladder, rises to the surface: smoke or hot air, and hydrogen gas in a balloon, rise in the air. A fish swims by its fins in water: a bird flies by its wings in the air. But on taking water from the vessel in which a fish swims, the creature falls to the bottom, and gasps a few moments, and dies: so, on exhausting the air from a vessel in which birds or butterflies are enclosed, their useless wings for a time will flap; but if the cruel experiment be continued, they will soon become motionless and for ever.

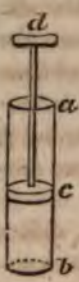
We proceed now to prove that air or gas, as a fluid, differs from the other fluids which we call liquids, only in the two circumstances of extreme lightness or rarity, and of being very extensively elastic, that is to say, the particles being so related, that pressure brings them much more nearly into contact, and on ceasing, allows them to regain their former distance.

Lightness of Air.

The lightness or rarity of atmospheric air, as it is found on the general surface of the earth, is such, that if, by the action of a pump, a bag of it holding a cubic foot, be emptied into the copper ball of an air-gun, the ball weighs about an ounce and a quarter more than before. The same volume of water weighs nearly one thousand ounces; so that common air is about eight hundred times lighter than water. Other gases, or substances in the aeriform state, have their various specific gravities, just as the same substances have when liquid or solid. Thus water in the form of air, and with the density which it has under the piston of a common steam-engine, is little more than half as heavy as common air: hydrogen is only one fourteenth part as heavy: and carbonic acid gas, which is the air that rises out of soda water, or brisk ale, or champaigne wine, is so much heavier, that even in the atmosphere, it may be poured out of one open vessel into another, as a liquid might, or more exactly as water might be poured out under oil.

Elasticity of Air.

A small bladder full of air may be pressed or squeezed between the hands until it is much reduced in size, and on relieving it from the pressure it will immediately resume its former bulk.



If a metallic tube or barrel of perfectly uniform bore, *a b*, and closed at *b*, be fitted with a moveable plug or piston *c*, which is covered with leather and oiled, so as to slide up and down without allowing the air to pass by its sides, the air between the piston and the close bottom *b* may be compressed to a hundredth or less of its usual bulk; but when allowed, will push the piston back again with the same force as it opposed to the condensation, and will recover the volume which it had before the experiment.

Again, if the plug at the commencement of the experiment were only an inch from the bottom, on drawing it up to the top, the inch of air beneath it would expand so as to occupy the whole tube, having become, of course, proportionally less dense.

If the question were proposed here, why the air, which admits of such various density, is found to have that certain degree of it met with at the surface of the earth? we answer, that as the water, in any place near the bottom of the ocean, is pressed with force exactly proportioned to the quantity of water above it, so the air at the surface of the earth bears the pressure of the superincumbent mass of air, and then, on account of its extensive elasticity, like the lowermost bags of cotton or wool in a great heap, it suffers that degree of compression which the superincumbent mass is calculated to produce. We shall see below, that the density of the air near the earth is changing with every circumstance which affects the weight of the atmosphere above, as winds, clouds, rain, &c., and that it bears relation to the altitude of the place of observation.

The tube with its piston, described as above, furnished with valves, becomes, according to the position of its valves, either a syringe for condensing air, or a pump for exhausting or removing it from any vessel; both operations depending on the elasticity of air.

A barrel and piston is a *condensing syringe*, when, in a passage of communication between the bottom of the syringe and a receiving vessel, there is a flap or *valve* allowing air to pass towards the receiver but not to return. The piston, therefore, at each stroke forces the fill of the barrel of air into the receiver. When the piston is lifted again after the stroke, air re-enters the barrel from the atmosphere, either through a valve in the piston, or through a small hole near the top of the barrel.

That useful contrivance, *a valve*, for whatever purpose used, and in whatever way formed, is in principle merely a moveable flap, placed on an opening, against which it is held by its weight, or by some other gentle and yielding force. Such a flap, it is evident, will allow fluid to pass only in one direction, *viz.* outwards from the opening, for fluid tending inwards must shut the flap, and press it the closer, the greater the tendency.

To convert a forcing syringe or pump into an exhausting syringe or pump, commonly called an *air pump*, it is only necessary to reverse the position of the valves: then, on the descent of the piston, all the air between it and the bottom, instead of entering the vessel as in the last case, escapes by a valve in the piston itself towards the atmosphere, and on the rising of the piston, a perfect vacuum would be left under it, but that the valve below, then opened by the elasticity of the air in the receiver, allows a part of that air to follow it. Thus, at each stroke, a quantity of the air, proportioned to the size of the pump, is removed from the receiver. In a good air-pump there are two similar pumping barrels, *a* and *b*, to quicken the operation of exhausting; and both pistons are worked by the reciprocating action of the same winch or handle *f*, turning the pinion *e*, which acts on the teeth of the piston rods *d* and *c*. Both pumps communicate with a tube *g h*, which at *h* rises tightly through the round

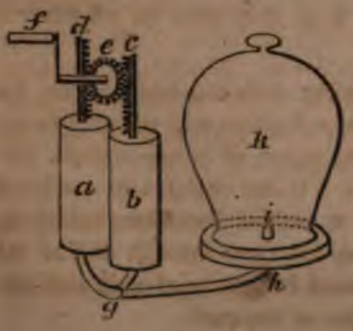


plate of the machine to *i*. This flat plate is so smooth, that a glass bell or *receiver k*, with a smooth ground lip, when placed upon it, forms an air-tight joining. On working the pump, such a bell is exhausted of its air, and fitted for showing the many interesting phenomena which the air-pump can display; and which will pass under review as we proceed. The supporting frame-work of the pump is not shown here.

The law of the elasticity of air, is, that its spring, or resistance to compression, is proportioned to its density, or the quantity of it collected in a given space. Hence, by finding in any case either the density of the air, or the spring, or the compressing force, we know all the three.

It has been ascertained by experiments described a few pages further on, that in the atmospheric ocean surrounding the earth, there are nearly fifteen pounds of air above every square inch of the surface of the earth: while the air near the earth, and bearing this superincumbent weight or pressure, has a density indicated by about an ounce troy to the cubic foot. We further find that such air is reduced to half its bulk, or becomes of double atmospheric density, by an additional pressure of fifteen pounds on the inch, and of triple density by triple pressure, and so forth; and on the other hand, that it dilates to double bulk if the pressure be diminished to half, and to any greater bulk, even beyond a thousand-fold, if the pressure be diminished in a corresponding degree: that air which bears a given force or pressure, acting always as a spring with that force on whatever it touches.

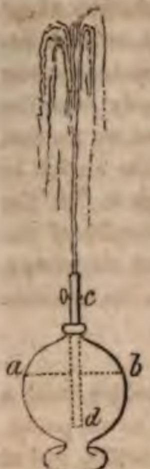
It is very important to be familiar with this truth or law, for it holds with respect to all aeriform fluids as well as common air, and throws light therefore on the action of steam-engines, air-guns, and all pneumatic machines. It also explains the condition of our atmosphere as to density at various elevations; telling us, for instance, that when a balloon has risen through half of the atmospherical mass, the air around it will be of only half the density which exists at the surface of the earth.

We know not exactly to what extent the rarefaction of air may go on the removal of pressure; in other words, at what distance the gravity of the particles becomes just a balance to their mutual repulsion; and therefore we know not exactly what the degree of rarity is at the top of our atmosphere; but we see that it must be exceedingly great, from the fact that the air left in the receiver of an air-pump has still spring enough to lift the valve of the pump, when there is less than a thousandth of the original quantity remaining. In the most perfect air-pumps, that the exhaustion may be as complete as possible, the machine itself is made to raise the valve.

The expansion of air is well illustrated by a bladder, with a very little air in it, placed under the receiver of an air-pump. On exhausting the receiver, the bladder gradually swells, and at last appears quite full: it will lift a weight laid upon it, and may even burst. A shrivelled apple treated in the same way becomes plump. The explanation of these phenomena is, that at first the air in the bladder or apple is condensed, like all air at the surface of the earth under the pressure of the superincumbent atmosphere; but its volume increases as that pressure is diminished by the air-pump:—it is rarefied exactly in the same proportion as the air which remains in the receiver surrounding it.

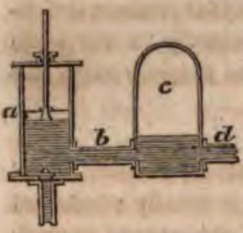
In the ball of an air-gun—which is a strong globular vessel of copper attached under the lock, the air is usually condensed thirty or forty times as much as in the atmosphere around; hence the pressure of elasticity tending outwards is thirty or forty times fifteen pounds on the inch, and when the valve is opened for an instant by the action of the lock, air issues and propels the charge with this force. The effect of air thus condensed nearly equals that of gunpowder, and one charge of the ball suffices for many shots.

If a bottle or vessel *a b*, partly filled with water, have a tube



c d passed tightly through its cork to near the bottom of the water; and if more air be then forced through this tube in any way, so as to accumulate in the upper part of the vessel; on turning the cock *c*, which opens the tube, the elasticity of the condensed air will press the water out as a beautiful jet, to a height proportioned to the density of the air. Or if such a vessel, with air of common density, be placed under a tall air-pump receiver, on working the pump so as to diminish the density of the air in the receiver, the jet of water will equally arise.—A table-lamp thus, by the pressure of condensed air, may be supplied with oil from a reservoir far below the wick: and lately an enema-syringe, and a shower-bath have been constructed on the same principle.

The elasticity of air is rendered very serviceable in connexion with great water-pumps, such as those used for the supply of cities. A pump throws its water by a distinct gush at each stroke, while the current through the pipe towards the city should be uniform. Now uniformity is attained by causing the gushes from the pump *a* to enter by *b* at one side of a large vessel *c*, of which the upper part is full of condensed air, and from the other side of which, at *d*, the water issues on its way. The air in this vessel (called the *air-vessel*) is condensed by the entering water, and its resisting elasticity forces the water along the pipe *d*. Each entering gush has only the effect of compressing the air a little more for the time, while the flow in the great pipe continues nearly uniform. The pump itself is made to take in a little air at each stroke, so that not only is the vessel always supplied, but some air is constantly passing on with the water, and effecting the highly useful purpose of giving an elasticity to the whole contents of the pipe and its ramifications.



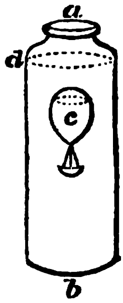
The same object is attained by the same means in the fire-engine used to check conflagration. In it there are generally several water-pumps working together, which throw their interrupted supply into an air-vessel, from whence it passes in a uniform jet to the point desired.

The compressibility and corresponding spring of air are remarkably exhibited in that singular contrivance of modern times, the *diving-bell*, in which men now descend with safety to considerable depths in the ocean, there to reside and labour, attaining many objects of high importance to them:—they recover sunken treasures,—they are enabled to pursue works of submarine architecture,—to construct light-houses and noble harbours, where formerly no foundations could have been laid, &c. The diving-bell, in point of utility, has proved a remarkable contrast to its sister invention—the balloon, which, although so wondrously bearing man aloft to the regions of the clouds, takes him there for little advantage, and often, as many accidents have proved, with danger to life.

The diving-bell is a large heavy open-mouthed vessel, with accommodation in it for one or more persons. It is let down into the water with its open mouth undermost, from a ship or barge fitted for its service. On first entering the water it appears full of air; but air being compressible according to the law now explained, and the pressure of the water around the descending bell increasing with the depth, the volume of the air gradually diminishes, and at thirty-four feet is reduced to half. The bell is then, of course, half full of water (unless more air be supplied,) and a person breathing in it, at each inspiration receives twice as much air into the lungs as when breathing at the surface. A constant supply of fresh air is sent down to the bell by a forcing-pump above; and the heated and contaminated air, which has served for respiration, and which rises to the top of the bell, is allowed to escape by a cock placed there for the purpose. The men who work at a distance from the bell have tubes of communication with it, by which they inhale the air required; and they allow the used air to rise through the water above them. A man cannot breathe comfortably by such a tube if he be either much above or below the level of the water in the bell: for if above, the air in the bell is more compressed than his chest, and is forced towards him so as to require an effort to control its admission; and if below, his chest is bearing greater pressure than the air in the bell, and he must therefore act strongly with the muscles of the ribs to draw the air down to him. A phenomenon similar to this takes place when two bladders of air are connected by a long tube, and immersed in water to unequal depths: the air is always strongly forced from the lower into the upper one, because the lower one is more forcibly pressed. The difficulty of pumping air down to the diving-bell, increases, of course, with the depth to which it has descended: for if the bell be so low that the water is pressing on the air in it with a force of fifteen pounds per inch (which would happen at thirty-four feet,) it is evident that a syringe or pump cannot inject more air unless it act with a force greater than this. Men now work in the diving-bell and about it with so little discomfort, that the wages of submarine labour are very little higher than of any other labour.

It is remarkable, when the use of the diving-bell has become so familiar, that a kindred and still more simple contrivance of the same class has not been introduced for certain purposes, particularly of sudden emergency, such as to aid in the recovery of the bodies of drowning persons. A ten-gallon cask, or vessel of any kind, filled with air, and made heavy enough to sink in water, with a breathing tube from it like that of a diving-bell, would be a provision of air for a man below water for ten minutes; and a man with it under his arm, might instantly descend from a boat, or walk from a shore, into water of any depth, to recover the body of a fellow-creature lately sunk, and in time probably to save the life, which a few minutes wasted in waiting or in unsuccessful dragging would suffer to be lost. The tube would issue from the upper part of the vessel, and there would be an opening at the bottom to allow water to enter to compress the air proportionally to the depth, and to replace it as used. The author would propose this as an addition to the apparatus of the Humane Society for the recovery of persons apparently drowned.—It shows the remoteness from common trains of thinking of the truths connected with the constitution of our atmosphere, when a means so simple and easily procured should never have been thought of or tried in any way by pearl-fishers, or by persons who gain their bread by diving to recover things dropped overboard in harbours or anchoring stations; all of whom have hitherto been limited to the single gulp of air taken on descending. In any case of a man working under water, cask after cask of air might be sent down, to enable him to remain as long as necessary.

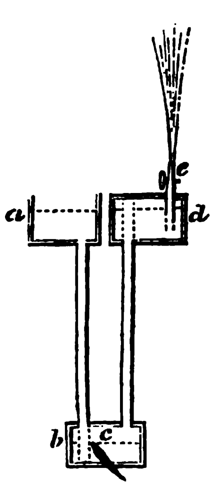
There is an exceedingly beautiful philosophical toy, of which the action depends chiefly on the elasticity of air; and as it moreover illustrates most of the laws of fluidity, it is deemed worthy of description here. It is a small balloon or thin globe of glass *c*, having an opening at the bottom, and its little car or basket hanging to it. If put to float in water while the globe contains air only, it is so light that half of it remains above the surface; but water may be introduced into the globe to adjust the specific gravity of the whole, so that it may be only a little less than that of water. If the balloon be then placed in a tall jar of water *a b*, the mouth of which is closely covered by bladder-skin or India-rubber tied upon it, on pressing such covering with the hand, the balloon will immediately descend in the water: it will rise again when the pressure ceases, and will float about, rising, or falling, or standing still, according to the pressure made. The reason of this is, that pressure on the top of the jar first condenses the air between the water surface and the cover; this condensation then presses upon the water below, and by influencing it through its whole extent, compresses also the air in the balloon-globe, forcing just as much more water into this as to render the balloon heavier than water, and therefore heavy enough to sink. As soon as the pressure ceases, the elasticity of the air in the balloon repels again the lately entered water, and the machine becoming lighter than water as before, ascends to the top. If the balloon be



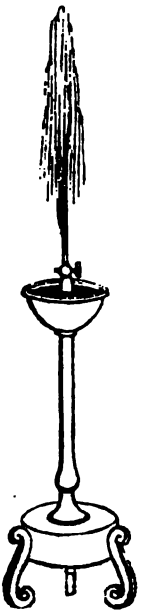
adjusted to have a specific gravity too nearly that of water, it will not rise of itself after once reaching the bottom, because the pressure of the water then above it will perpetuate the condensation of the air which caused it to descend. It may even then, however, be made to rise again by inclining the water-jar to one side, so that the perpendicular height of water over it shall be diminished.

This toy proves many things—the *materiality* of air, by the pressure of the hand on the top being communicated to the water below through the air in the upper part of the jar—the *compressibility* of air, by what happens in the globe just before it descends—the *elastic force* of air when, on the pressure ceasing, the water is again expelled from the globe—the *lightness* of air, in the buoyancy of the globe:—it shows also that in a fluid *the pressure is in all directions*, because the effects happen in whatever position the jar be held—it shows that *pressure is as the depth*, because less pressure of the hand is required the farther that the globe has descended in the water—and it exemplifies many circumstances of *fluid support*. A young person, therefore, familiar with this toy, has learned the leading truths of hydrostatics and pneumatics, and has had much amusement as well as instruction.

On the same principle as the balloon now described, three or four little figures of men may be formed of glass, hollow within, and having each a minute opening at the heel, by which water may pass in or out. If these be placed in a jar as the balloon was, and be adjusted by the quantity of water admitted into them, so that they shall differ a little from each other in specific gravity; when pressure is made on the cover of the jar, the heaviest figure will descend first, and the others will follow in succession; and they will stop or return to the surface in reverse order when the pressure ceases. A person exhibiting these figures to spectators who do not understand them, seems to have the power of ordering their movements by his will. If the jar containing the figures be inverted, and the cover be placed over a hole in the table, through which, unobserved, pressure can be made by a rod rising through the hole and obeying the foot of the exhibitor, the most amusing and surprising evolutions may be produced among the little men, in perfect apparent obedience to word of command.



The beautiful fountain, called the fountain of Hero, by which water is made to spout far above its source, depends for its action upon the resisting elasticity of compressed air. The vessel *d* is first filled with water, while *b* and *a* contain air only. On then pouring water into *a*, the water of *d* darts upwards through the jet pipe *e*, to an elevation nearly equal to the length of the tube from *a* to *b*. The reason is, that the water from *a* descends by the tube to *b*, and compresses the air in *c*; which compression conveyed along the other tube from *c* to *d*, acts on the water in the vessel *d*, and causes it to jet. The pressure being produced by the column of water *a b*, the jet is proportioned to the length of that column.—This fountain may have its parts concealed under a variety of graceful forms, as that here represented; and then it becomes a beautiful ornament among flowers in a summer drawing-room. It may be made to play for an hour or more and will always recommence on the water being shifted from the low to the high reservoir.



Having now explained the two peculiarities which distinguish aeriform from other fluids, *viz.* their *lightness* and extensive *elasticity*, we proceed to show that they have the four other properties already described under hydrostatics, as belonging to fluids generally: and first

"*Pressure in all directions.*" (*Read the analysis at pages 236 and 282.*)

A quantity of air or gas shut up in any vessel, and compressed, is equally affected throughout, and its tendency to escape from the pressure is equal in all directions, as is proved by the force necessary to keep similar valves close wherever placed. Hence the hydrostatic press and hydrostatic bellows described in last section, which depend for their action on this law, may be worked by air or gas as by a liquid.

Owing to this law, air, when allowed, will always rush from where there is more pressure to where there is less. The actions of the common fire bellows, and of the animal chest in breathing, blowing, sucking, &c. are so many instances.

The suddenness with which any compression made on part of a confined aeriform fluid is communicated throughout the whole, is strikingly seen in the simultaneous increase or burst of all the gas lights over an extensive building, or even along a whole street, at any instant when the force supplying the gas is augmented.

Many very interesting illustrations of the fluid pressure of air being in all directions will occur under the next head, joined with proofs of the atmospheric pressure being as the depth.

"*Pressure as the depth.*"

On first approaching this subject, a person is naturally surprised to find the depth of the atmosphere spoken of as something perfectly ascertained, although nobody can ever have approached the surface to measure it: but science often furnishes means of discovering precise truth, in cases where ignorance would not even dream of the possibility of making an approximation. It may facilitate the apprehension of this point as regards air, to describe at the same time a similar case as regards water.

The bottom of a lake, supports all the water in the lake, and each portion bears just the weight of the water directly over it: a means then of ascertaining the weight or pressure of water on any portion of the bottom, would tell how much water there stood over that portion, and by the known relation of the weight and bulk of water, would tell also the depth at that part. In like manner, the ocean of air which surrounds the globe rests with its whole weight upon the surface of the globe, and each portion of the surface bears its correspondent share: if we ascertain then the pressure of the atmosphere on a given extent of surface, we find how much air is standing directly over it; in other words, the weight of a column of air resting on such surface as its base, and reaching to the top of the atmosphere. Having then the weight of the whole column, and finding the weight of a given bulk of it at the bottom (ascertained as described at page 277) and knowing the law of aerial elasticity (explained at page 287,) we determine the depth or height of the column by a simple calculation. Now accurate experiments show that there are nearly fifteen pounds of air over every square inch of the earth's surface; producing the same pressure as would be made by a depth of water of thirty-four feet, or by a depth of quicksilver of thirty inches; and from this fact, and the ascertained lightness and elasticity of air, we know that its depth on earth must be nearly fifty miles, which, as already stated, is about as much in relation to the size of the earth as a tenth of an inch is to a globe of one foot diameter. The remaining part of this section has chiefly to trace the effects of such a mass of matter resting upon the earth's surface, and embracing and compressing every object placed there.

Water is a substance much more obvious to the human senses than air, and which is constanly under observation; yet many of its most important agencies escape the notice of common observers. Few persons, for instance, discover of themselves the law explained in the last section, of the pressure in water being proportioned to the depth: but when they find that a piece of cork plunged deep into it is compressed to much smaller bulk, and that strong empty vessels of glass, or even of metal, under the same circumstances, are crushed inwards, and that pieces of sunken wood are filled with water through all their pores, so as to become heavier than stone, &c., their minds are roused to a sense of the important fact. If the truths of hydrostatics thus escape notice, we need not wonder that those of pneumatics escape still longer.

If a common drinking glass or tumbler be filled with water, and a piece of bladder-skin be tied closely over its mouth, on allowing it to sink to the bottom of a mass of water, and to stand there with its mouth upwards, the bladder exhibits no sign of being pressed upon, although it bears on its upper side the whole weight of the water directly above it: the reason being that the water beneath the bladder resists just as strongly as that above presses: but if by means of a syringe or pump, the water were extracted from within the glass, the bladder itself would then have to bear the whole pressure of the water above it, and would probably be torn or burst. The degree of pressure, and consequently the depth of water, in such a case, might be ascertained, by placing some support, of which the action could be measured, under the bladder to sustain it after the removal of the interior water.—Now this case may be exactly copied in our atmosphere or sea of air. A glass held in the hand is immersed in the fluid air, and is full of it, as the other glass was full of water: its mouth may be covered over with bladder, and no external pressure will be apparent, because there is a resistance of the air within, just equal to the pressure of the air on the outside:—but if the air be extracted from under the covering, by means of an air-pump, the bladder is first seen sinking down and becoming hollow from the weight of the air over it, and at last bursting inwards with a great noise or crack. By placing a circular piece of wood under the bladder-skin, for it to rest on, and a spring of known force to support the wood, we may ascertain very nearly the weight and pressure of the air over it:—the problem, however, can be solved more elegantly and accurately by means of the barometer described further on. This phenomenon of atmospheric pressure is often shown by placing the hand on the mouth of a glass so as to cover it closely, and then extracting the air from underneath the hand: the weight of the atmosphere holds the hand down upon the mouth of the glass with a force of fifteen pounds to the inch.

As should follow, from the pressure of fifteen pounds per inch thus detected at the surface of the earth being the weight of our superincumbent atmosphere, we find that exactly as we rise from the earth, the pressure diminishes. This fact now furnishes the readiest means of ascertaining the height of mountains and of balloon ascents, as will be explained in considering the barometer.

After the many explanations here given of fluid pressure being equal in all directions, it is almost superfluous to remark that the downward weight of the atmosphere becomes an equal pressure in all directions. This is seen in the fact of the bladder described above being as readily burst if turned sideways as if turned directly upwards. Every body or substance, therefore, on the surface of the earth, dead or living, solid or fluid, is compressed with this force. In general the pressure on one side of a body is balanced by the equal pressure on the other, so that no sensible effect follows; and it is on this account that philosophers were so long in discovering it at all, and that half-informed persons are still disposed to doubt its existence; but the proofs offered on all sides to the now awakened attention are irresistible. We shall first speak of

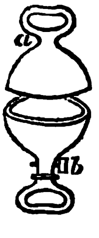
“*Atmospheric pressure on solids.*”

The atmosphere, then, presses on the two sides of a plate of glass or metal, with force of fifteen pounds on the inch. Under ordinary circumstances no sensible effect follows, because the opposite pressures counterbalance; but if two plates of smooth glass or metal be laid against each other, and the air be excluded from between them, they cannot be separated by less force than fifteen pounds per inch of their surface.

In like manner to draw the piston of a syringe from the bottom of its barrel, while no air is allowed to enter between them, requires force of fifteen pounds to the square inch of surface of the piston. But if the experiment be made in the exhausted receiver of an air pump, the piston falls by its own weight. It is pushed back immediately on re-admitting the air. Wherever a vacuum is produced at the surface of the earth, there is an external pressure, to the extent stated, seeking admittance all round.

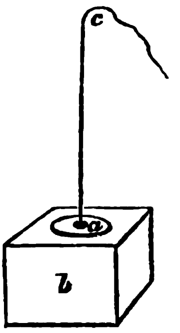
An air-pump receiver of five inches diameter has nearly twenty square inches of surface in its upper part or roof, and bears a weight or pressure of atmosphere, of twenty times fifteen, or three hundred pounds. While it has air within it, this pressure is exactly balanced and is not sensible; but when exhausted on the plate of the air-pump, it is pressed against the plate with this force. As the atmospheric pressure is in all directions, the pump-plate of course is equally pressed upwards against the receiver, and the sides of the receiver are pressed towards each other. This explains why air-pump receivers must be made arched or of dome-shape to withstand the great pressure. A flat piece of glass of great thickness, laid upon the upper mouth of a receiver, so as to form an air-tight cover to it, is broken instantly by exhausting the air beneath; and a bottle or receiver with flat sides suffers in the same manner.

Illustrative of this pressure on solids is the experiment of the Magdeburgh hemispheres, as it is called. Two hollow half globes of metal *a* and *b*, are fitted to each other, so that their lips when touching may be air-tight. While there is air between them or within, resisting the pressure of the outward air, they can be separated from each other without difficulty; but when the air is exhausted from within by the air-pump, a force is required to separate them of as many times fifteen pounds as there are square inches in the area of the mouth. The air is extracted by unscrewing one of the handles at *b*, and then connecting the remaining stalk (which is hollow, and has a stop cock) with the air-pump.—This experiment merits recollection, because it was one of the first which drew attention to the material nature and properties of the air; and it astonished the world. Otto de Guericke, of Magdeburgh, the inventor, had hemispheres made



of a foot in diameter, and once when he exhausted them, on the occasion of a public exhibition, six coach-horses of the Emperor were unable to pull them asunder. There being no air-pump in his time, Guericke emptied the balls of their air by first filling them with water, and then extracting the water by a common pump or syringe applied at the bottom.

It is a phenomenon of the same kind as the last, when a boy with his foot presses a circular piece of wet leather *a*, against a large stone *b*, and then pulls as if to detach it at a cord *c*, rising from its centre. If the leather be so close in its texture that air cannot pass through it, and stiff enough not to be puckered or drawn together, he must exert a force before detaching it, of as many times fifteen pounds as there are square inches of surface covered by it, for such is the weight or pressure of the air over it, while there is no counterbalancing pressure underneath nearer than on the other side of the stone. If this *sucker*, as it has been called, be applied to a loose stone which weighs less than now mentioned, the stone may be lifted by it. A very large *sucker* applied upon a rock or wall, would resist the pull of horses like the Magdeburgh hemispheres.



The simple contrivance now described, and which may be called a *pneumatic tractor*, seems well suited to various purposes of surgery. It might assist, for instance, in raising depressed portions of a fractured skull, and might thus sometimes save the operation of trepanning:—for such a purpose it would be preferable to a small cupping-glass, from its being perfectly inactive, except during the instants when pulled at; whereas the cupping-glass, by keeping up a continued flow of blood to the part, might do injury.* In cases where cupping glasses, although desired, were not attainable, the tractor might be made to answer for them, both to prepare a part for scarification, and afterwards to increase the flow of blood from the punctures. There is another surgical application of the tractor spoken of in the last *section* of the present *part*, which the professional reader is desired to consult immediately.

---

* It does not appear to us very evident, that either the pneumatic tractor or the cupping-glass, especially the former, may be employed with safety for rais-

It is from having feet that act on the principle of the tractor, that certain insects can move along ceilings with their bodies hanging downwards; and there are fishes which attach themselves to rocks, or other objects, by a similar action.

If two pneumatic tractors be applied to each other, men pulling opposite ways, to separate them, must act with a force of fifteen pounds to the square inch of the surface of contact, as if they were separating the Magdeburgh hemispheres.

The action of this tractor may be well illustrated by an experiment made in a vessel containing a liquid. If a body with a flat surface be applied to the flat bottom of the vessel so as perfectly to exclude the liquid, the body bears the whole weight of liquid directly over it, and cannot be detached without force at least equal to this. The case is striking when a flat piece of cork is pushed against the smooth bottom or side of a vessel containing mercury, and is found not to rise again when the hand is withdrawn from it, but to be firmly held down by the weight of mercury. We have to remark in such experiments made in vessels open to the air, that the weight of the atmos-

---

ing a depressed portion of skull. If this part be denuded of the scalp, and be of sufficient size for the cupping-glass to be applied to it alone, this instrument may be employed sometimes under such circumstances with advantage, but under any other it can only be productive of injury. Under the circumstances noticed, the pneumatic tractor will probably be found less useful, since the pressure necessary to expel the air from between the fracture and the depressed portion of cranium, will in most cases aggravate the compression of the brain, and may even produce fatal consequences; and under all other circumstances it is clearly inadmissible.

AM. Ed.

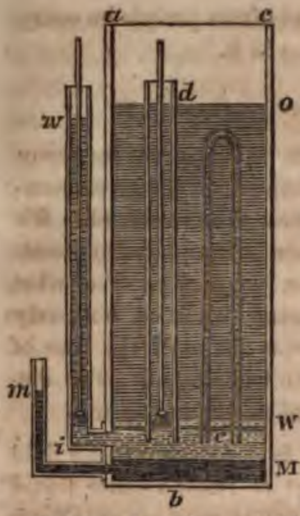
phere over the liquid adds a pressure of fifteen pounds on every inch of the surface of a body immersed in it.

"*Atmospheric pressure on liquids.*"

The pressure of the atmosphere on liquids produces many important effects, and now that we comprehend them, we wonder that they should have been so long misunderstood. We have familiar examples of it in the action of pumps and syphons. All such phenomena, in former times, were referred to what was called *nature's horror of a vacuum*, or to an obscurely imagined *principle of suction.* It was not until the time of Galileo that their true nature began to be detected. The discovery has led to many very important results in the arts.

Persons may at first have difficulty in conceiving that a fluid so rare and subtile as air should effect or resist a dense liquid like water: but the action of air in contact with water is familiarly shown in the facts, that a vessel does not fill with water when plunged, with the open mouth downwards, from the air into water, and that when a tube open at both ends has been partially immersed in water, and therefore partially filled, the water can be forced out of it by blowing air with the mouth in at the upper end. Then it may be recollected that a hundred pounds of feathers are as great a load as a hundred pounds of lead.

That there are fifteen pounds of air above every square inch of the earth's surface, has already been explained, while we were considering the atmospheric effects upon solids; and we now proceed to show that many of the phenomena among liquids, which long appeared so mysterious, are merely the necessary consequences of the same pressure upon them. It will facilitate the comprehension of these effects, if we first view them as they may be produced by more visible agents, *viz.* by one liquid pressing upon another; and for this purpose the author has contrived the apparatus represented below, in which a layer of oil rests upon a layer of water, and both these upon a layer of mercury.



It has already been shown, that an ocean of oil spread over the earth, to have the same weight as our atmosphere, would require to be about thirty-seven feet deep. A vessel, then, *a b c*, with water in it up to the level W, and with thirty-seven feet of oil above this, up to the level *o*, is fitted to illustrate many of the phenomena of atmospheric pressure. The following are the seven principle cases.

1st. The weight of the oil pressing with a force of 15 *lbs.* per inch on the water at W, would not at all disturb the level surface of the water.—Neither does the weight of the atmosphere of 15 *lbs.* per inch disturb any liquid surface.

2d. In proportion as the oil were poured into the vessel *a b c*, the water would rise in the tube *i w*, as already explained by the figure at page 261 (which see;) so that when there were thirty-seven feet in height, or fifteen pounds in weight of oil on the inch, the water in *i w* would stand thirty-four feet high. If these thirty-four feet of water where then lifted out of the tube by a plug or piston drawn up from the bottom of it at *i*, a second equal quantity would be pressed up by the oil, and the tube and piston would constitute a pump.—Now when the atmosphere instead of the oil is allowed to press upon the water-surface in such a vessel, but is excluded from the tube, the water still rises in the tube thirty-four feet, as in the last case; and if this quantity be lifted out of the tube by a piston, a second equal quantity is pressed up, and the tube and piston become a complete example of the common *lifting* or *sucking-pump*.

3d. If there were a quantity of mercury or quicksilver at the bottom of the vessel *a b c*, filling it up to the level M, and if a tube *i m* issued from under this level, the mercury would rise in this short tube as the water did in the larger; but by reason of its greater specific gravity it would only reach a height of thirty inches while the water stood at thirty-four feet.—Now thirty inches of mercury is the height of column which the atmospheric pressure acting in the same way really produces, as is seen in a similar apparatus made expressly for measuring that pressure, and called a *barometer*, or *measure of weight*.

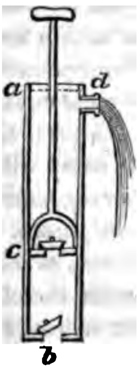
4th. If a tube *d*, of an inch square, and open at both ends, were plunged into the oil, it would of course always be full up to the level of the oil on the outside of it; and if it were pushed low enough to enter the water at W, it would just contain fifteen pounds of oil resting on the water-surface at its mouth; which surface would therefore be bearing a weight of fifteen pounds, like every inch of the surface around, but would not yield, owing to the force with which it tended upwards to escape from the pressure corresponding to its depth in the oil. Then if, by a piston or plug at *e* in the tube *d*, the fifteen pounds of oil were lifted out of it, water would rise into it until enough had entered to reproduce the pressure of fifteen pounds on the surface below as before; that is to say, the water would rise thirty-four feet, as in the external tube *w i*. This internal tube and piston again would form a *pump*.—In like manner, when a tube open at both ends is plunged from the air into water, the air presses on the surface of the water within the tube, as on the surface around it, with a force of fifteen pounds to the inch, and the two surfaces are not affected by the equal pressures; but if, by a piston, we lift the air out of the tube, as we suppose the oil lifted in the last experiment, the water will then rise thirty-four feet, following the piston. This arrangement of parts is the most useful for the *lifting* or *household pump*.

5th. If a common bottle or a vessel of any other shape, as the bent tube *c*, were filled with water, and plunged under the oil until its mouth or mouths reached below the water-surface at the level W, it would remain full of water, owing to the pressure of the oil surrounding it.—For a similar reason, any such vessel or tube, surrounded only by the air, when filled with water, and placed with its mouth or mouths under the surface of water, remains full; and if one end of the tube be longer than the other, a current is established in it;—the contrivance being then called a *syphon*.

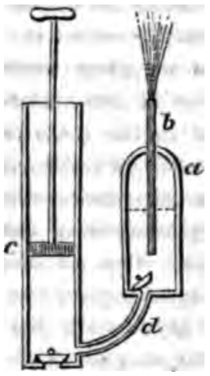
6th. A fish in the water below the level W would be bearing the pressure of the oil from O to W, as well as the pressure of the water. So a fish in water open to the air, is bearing the atmospheric pressure of *fifteen pounds per inch*, in addition to that of the water itself. This is proved by extracting the air from over water in which a fish is swimming: for then the air-bag of the fish, situated near its under side, as already described, immediately dilates and turns the fish upon its back.

7th. To separate the Magdeburgh hemispheres, or to produce a vacuum in any way, under the water level W, would require force proportioned to the weight of oil above (supposing the oil to be protected from the pressure of the atmosphere,) in addition to that required on account of the water:—and to separate the Magdeburgh hemispheres under any water-surface pressed upon by the atmosphere, a force is required of *fifteen pounds per inch* beyond what would balance the effect of the water itself.

The following remarks illustrate more minutely some of the objects which we have just been explaining.

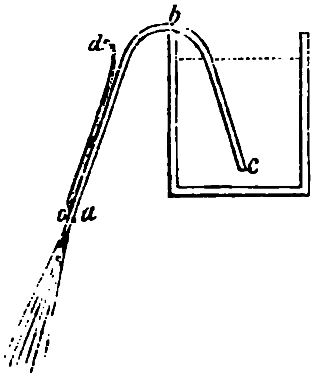


The common *lifting-pump* (or *sucking-pump* as it used to be called,) is then merely a barrel *a b*, with a close-fitting plug or piston in it *c*. When the lower end *b* is plunged into water, and the piston is drawn up from the bottom, the atmosphere being prevented from pressing on the surface of the water within the tube, the pressure on the surface external to the tube, drives the water up after the piston. That the water which thus rises may not fall again, there is a valve or flap at the lower part of the pump-barrel *b*, which allows the water to pass only upwards; and that the piston may be allowed to pass downwards through the water in the pump-barrel, to repeat its stroke, there is in it a similar valve. The piston, in rising during the second stroke, causes all the water above it to run over at the spout *d*.—Formerly a lifting-pump was said to act by *sucking* the water up from the well beneath it; the true meaning of which phrase we now know to be, that the piston merely lifts the air which was pressing on the water within the barrel, and allows the water to rise there in obedience to the external pressure of the air around. The reason is now apparent why, in the lifting-pump, the water will only follow the piston to a certain elevation.

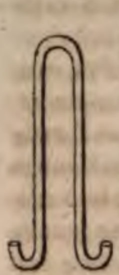


When the piston of a pump is solid, or without a valve, as at *c*, the machine is called a *forcing-pump*. The water rises beneath the piston, as already explained, but then, as it cannot pass through the descending piston, it is forced into another direction, as to *d*. A forcing-pump can bring water from only thirty-four feet below the piston, but can send it to any elevation. In forcing-pumps, it is usual to make the water enter an air-vessel *d a* (already explained at page 290,) from which it issues by the elasticity of the air, through the pipe *b*, in a nearly uniform stream.

The animal action of sucking is an approximation to what we have described in the lifting-pump. The difference is, that the chest or mouth can make only a partial vacuum, and therefore cannot raise a liquid very far.



A syphon remains full of liquid, although raised above the general surface of the liquid, as explained above. For common purposes, a syphon is made of the form here represented, *viz.* a bent tube *a b c*, with one end longer than the other. To use it, the end *c* is first immersed in liquid, and the end *a* being then stopped for the time with the finger, the air is extracted by the mouth or otherwise, through the small tube *a d*, allowing the atmosphere immediately to fill the whole tube with liquid from *c*. If the instrument be then left to act, the liquid will run from the longer leg, until the shorter has drunk up all within its reach. If both extremities be immersed in liquid, and in different vessels, the liquid will only be at rest in the syphon when the surfaces in the two vessels are brought to the same level. A syphon is sometimes made with both legs equal and turned up, as here represented, so that it remains full of liquid when removed from the vessel, and therefore is always ready for action. As it is the same cause which lifts the water in a pump and in a syphon, the top of a syphon must evidently be within thirty-four feet of the water-surface below. In the syphon, as in the cases of balancing liquids, described at page 261 (which see,) the comparative diameters of the legs is of no importance, nor their oblique length—the perpendicular heights alone of the two columns indicating the necessary relation. This truth is well exemplified in what may be called the *syphon-paradox*, an exact counterpart of the paradox of the "Hydrostatic Bellows," already explained The syphon-paradox may be exhibited by reversing the apparatus of the bellows. If this apparatus be filled with water in the ordinary way (see page 240,) and be then turned so that the tube becomes like the long leg of a syphon, the little stream of water issuing from it at *a* will lift as great a weight suspended *from* the board *d*, as the same slender column in the standing position can lift *upon* the board. Farther illustrative of the atmospherical pressure exerted in producing this effect and in rendering a syphon active, we may advert to the striking fact, that a long small tube of water screwed into the side or bottom of a close cask of water so as to communicate with it, and then allowed to discharge like the long leg of a syphon, will cause the cask to be burst inwards, just as the same tube screwed into the top of the cask, as represented at page 240, would cause the cask to be burst outwards.



The syphon is very useful for drawing off liquids, where there is a sediment that should not be disturbed, or where it is desirable not to make an opening in the vessel below. A large syphon would empty a lake or mill-pond over its bank without injuring the bank.

There is a pretty syphon-toy made, called a Tantalus' cup, having a standing human figure in it, which conceals a syphon. The syphon rises in one leg of the figure to reach the level of the chin, and then descends in the other to pierce the bottom of the cup towards a reservoir below. On pouring water into the cup, the syphon begins to act as soon as the water reaches the chin of the figure, and the cup is emptied as if by magic.

Among the infinitely varied water-drains or courses in the bowels of the earth, some are syphons, and hence produce what are called intermitting wells or fountains. These may alternately run for a day, and cease for two or three days, or for longer or shorter periods, according to the comparative magnitudes of the collecting reservoir and the drain. The reservoir may be an internal cave of a mountain, receiving a regular supply of water by a slow filtering of moisture from above, and the drain must be a syphon-formed channel, which, when in action, carries off the water faster than it is supplied. There are some fountains that flow constantly, but at regular intervals have a remarkable increase. In them a common spring must be joined with a syphon-spring.

The author has suggested an application of the syphon, which obviates a strong objection to the high operation for stone, as explained in the next medical section.

The following facts have close relation to those now explained, as further illustrative of atmospheric pressure on liquids.

A long glass of jelly, if inverted and placed with its mouth just under the surface of warm water, will soon be found to have lost the jelly, but to be full of water in its stead. The jelly is heavier than water, and when melted by the heat sinks down to be replaced by water from below, sent up by the atmospheric pressure.

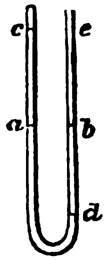
The slaves in the West-Indies steal rum, by inserting the long small neck of a bottle full of water through the top-aperture of explained, by that which is immediately below its mouth:—now a flat fish resting closely against the mouth of the tube, would evidently be bearing on its back the whole of this weight—perhaps one hundred pounds; but the fish would not thereby be pushed away, nor would it even feel its burden, because the upward pressure of the water immediately under it would just counterbalance the weight, while the lateral pressure around would prevent any crushing effect of the upward and downward forces. But if while the fish continued in the situation supposed, the hundred pounds of water were lifted from off its back by a piston in the tube, the opposite upward pressure of one hundred pounds would at once crush its body into the tube. At a less depth, or with a smaller tube, the effect might not be fatal, but there would be a bulging or swelling of the substance of the fish into the mouth of the tube. In air and on the human body a perfectly analogous case is exhibited. A man without pain or peculiar sensation, applies his hand closely to the opening of a tube, or to the mouth of any vessel containing air, but the instant that the air is withdrawn from within the tube or vessel, the then unresisted pressure of the air on the outside fixes the hand upon the vessel's mouth, causes the flesh to swell or bulge into it, and makes the blood ooze from any crack or puncture in the skin.

These last few lines describe closely the surgical operation of *cupping:* the essential circumstances of which are the application of a cup or glass with a smooth blunt lip, to the skin of any part, and the extraction, by a syringe or other means, of a portion of the air from within the cup. To some minds the exact comprehension of this phenomenon may be facilitated, by considering the similar case of a small bladder or bag of India-rubber full of any fluid and pressed between the hands on every part of its surface except one:—at that one part it will swell, and even burst if the pressure be strong enough. So in cupping, the whole body, except the surface under the cup, is squeezed with a force of fifteen pounds to the square inch, while in that one situation the pressure is diminished according to the degree of exhaustion in the cup, and the blood consequently accumulates there. The application of a cup with exhaustion only, constitutes the operation called *dry-cupping*. To obtain blood, the cup is removed and the tumid part is cut into by the simultaneous stroke of a number of lancet points; and the cup is afterwards used as before, so that the blood may rush forth under the diminished pressure. The partial vacuum in the cup may be produced either by the action of a syringe, or by burning a little spirit in the cup and applying it while the momentary dilatation affected by the heat has driven out the greater part of the air. The human mouth applied upon any part becomes a small cupping machine, and formerly, in cases of poisoned wounds, was used as such. Our present perfect cupping glasses, of stronger and more permanent operation, are not yet always used, as they might be, to assist in removing the poison after the bites of rabid or venomous animals.

The author has suggested an extension and modification of the operation of dry-cupping, which he believes will prove an important remedy in the hands of the medical practitioner. It is intended as a substitute for bleeding, in cases where blood can ill be spared, and in certain cases of inflammatory disease, as a more sudden and effectual check than even bleeding itself. It is explained in the next medical section of this work.

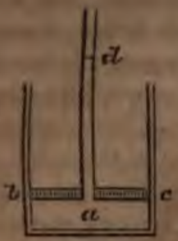
The atmospheric pressure on living bodies produces an effect which is rarely thought of, although of much importance, *viz.* its keeping all the parts about the joints firmly together by an action similar to that on the Madgeburgh hemispheres. The broad surfaces of bone forming the knee joint, for instance, even if not held together by ligaments, could not, while the capsule surrounding the joint remained air-tight, be separated by a force of less than about a hundred pounds; but on air being admitted to the articular cavity, the bones at once fall to a certain distance apart. In the loose joint of the shoulder, this support is of greater consequence. When the shoulder or other joint is dislocated, there is no empty space left, as might be supposed, but the soft parts around are pressed in, to fill up the natural place of the bone. When at high bone is dislocated, the deep socket called the acetabulum instantly becomes like a cupping glass, and is filled partly with fluid and partly with the soft solids. In all joints it is the atmospheric pressure which keeps the bones in such steady contact, that they work smoothly and without noise.

The barometer, we have seen at page 304, is a column of fluid supported in a tube by the pressure of the atmosphere, and therefore indicating most exactly the degree of that pressure. It is an instrument now of such importance, both in a scientific point of view and in the business of common life, that for the sake of minds which conceive such subjects with difficulty we shall add here the two following further illustrations of its nature.



If mercury be poured into a bent tube open at both ends it will stand at the same level in the two legs, as at *a* and *b*, and the air will be pressing on the two surfaces at *a* and *b* with equal force of 15 *lb.* per square inch. If the air be then removed from one leg *a*, by a piston or otherwise, while it continues to press in the other leg *b*, the mercury will be pushed down in *b*, until the growing height of the column in *a* produce a weight so much greater than that in *b*, as just to counteract the pressure: now this takes place, in fact, when the mercury in *a* stands about thirty inches higher than in *b*: that being the height of a column of mercury weighing 15 *lb.* on the square inch. If the top of the tube *a* were then closed permanently, the mercury would for ever remain in it, marking most perfectly the atmospheric pressure; now this construction, after the empty and useless part of the tube above *d* is cut off, forms a common barometer. The exact altitude of the mercury in it is known by observing how much the surface near *c* is higher than that near *d*. Occasionally, in such a barometer, a little float is placed on the mercurial surface at *d*, and is caused by a thread passing from it, to move an index like the hand of a clock, which tells the change of elevation. This modification is called the *wheel barometer*.

Again, as a quantity of water at *a* in the bottom of a closed pump-barrel, if pressed upon by the piston *b c*, of which the



rod *d* were hollow or tubular, would rise in the rod to a height proportioned to the pressure made by the piston: so, in a straight exhausted barometer-tube, which is as this hollow piston-rod, the mercury or water rises, because the atmospheric pressure around it is as the piston forcing the fluid up. To make a barometer of this kind it is only necessary to procure a glass tube about three feet long, and close at one end, and then having filled it with mercury, to plunge its mouth (stopped by the finger while turning) into a small cup or basin of mercury:—the fluid falls away a little from the top of the tube, leaving a vacuum there, and stands at the elevation which the atmospheric pressure is fitted to maintain. We know, from the law of hydrostatics already explained, that it is of no importance, in such a case, what the shape, or inclination, or size of the tube may be, as only the perpendicular height can measure or be measured by the pressure.

Galileo had found that water would rise under the piston of a pump to a height only of about thirty-four feet. His pupil Torricelli conceiving the happy thought, that the weight of the atmosphere might be the cause of the ascent, concluded that mercury, which is about thirteen times heavier than water, should only rise under the same influence to a thirteenth of the elevation:—he tried and found that this was so, and the mercurial barometer was invented. To afford further evidence that the weight of the atmosphere was the cause of the phenomenon, he afterwards carried the tube of mercury to the tops of buildings and of mountains, and found that it fell always in exact proportion to the part of the atmosphere left below it;—and he found that water-pumps in different situations varied as to sucking power, according to the same law.

It was soon afterwards discovered, by careful observation of the mercurial barometer, that even when one remained in the same place, it did not always stand at the same elevation; in other words, that the weight of atmosphere over any particular part of the earth was constantly fluctuating; a truth which, without the barometer, could never have been suspected. The observation of the instrument being carried still farther, it was found, that in serene dry weather the mercury generally stood high, and that before and during storms and rain it fell:—the instrument therefore might serve as a prophet of the weather, becoming a precious monitor to the husbandman or the sailor.

The reasons why the barometer falls before wind and rain will be better understood a few pages hence; but we may remark here, that when water which has been suspended in the atmosphere, and has formed a part of it, separates as rain, the weight and bulk of the mass are diminished: and that wind must occur when a sudden condensation of aeriform matter, in any situation, disturbs the equilibrium of the air, for the air around will rush towards the situation of diminished pressure.

To the husbandman the barometer is of considerable use, by aiding and correcting the prognostics of the weather which he draws from local signs familiar to him; but its great use as a weather-glass seems to be to the mariner, who roams over the whole ocean, and is often under skies and climates altogether new to him. The watchful captain of the present day, trusting to this extraordinary monitor, is frequently enabled to take in sail and to make ready for the storm, where, in former times, the dreadful visitation would have fallen upon him unprepared. —The marine barometer has not yet been in general use for many years, and the author was one of a numerous crew who probably owed their preservation to its almost miraculous warning. It was in a southern latitude. The sun had just set with placid appearance, closing a beautiful afternoon, and the usual mirth of the evening watch was proceeding, when the captain's order came to prepare with all haste for a storm. The barometer had begun to fall with appalling rapidity. As yet, the oldest sailors had not perceived even a threatening in the sky, and were surprised at the extent and hurry of the preparations: but the required measures were not completed, when a more awful hurricane burst upon them than the most experienced had ever braved. Nothing could withstand it; the sails already furled and closely bound to the yards, were riven away in tatters; even the bare yards and masts were in great part disabled; and at one time the whole rigging had nearly fallen by the board. Such, for a few hours, was the mingled roar of the hurricane above, of the waves around, and of the incessant peals of thunder, that no human voice could be heard, and, amidst the general consternation, even the trumpet sounded in vain. In that awful night, but for the little tube of mercury which had given the warning, neither the strength of the noble ship, nor the skill and energies of the commander, could have saved one man to tell the tale. On the following morning the wind was again at rest, but the ship lay upon the yet heaving waves, an unsightly wreck.

The marine barometer differs from that used on shore, in having its tube contracted in one place to a very narrow bore, so as to prevent that sudden rising and falling of the mercury, which every motion of the ship would else occasion.

Civilized Europe is now familiar with the barometer and its uses, and therefore, that Europeans may conceive the first feelings connected with it, they require almost to witness the astonishment or incredulity with which people of other parts still regard it. A Chinese once conversing on the subject with the author, could only imagine of the barometer, that it was a gift of miraculous nature, which the God of Christians gave them in pity, to direct them in the long and perilous voyages which they undertook to unknown seas.

A barometer is of great use to persons employed about those mines in which *hydrogen gas*, or *fire-damp*, is generated and exists in the crevices. When the atmosphere becomes unusually light, the hydrogen being relieved from a part of the pressure which ordinarily confines it to its holes and lurking-places, expands or issues forth to where it often meets the lamp of the miner and explodes to his destruction. In heavy states of the atmosphere, on the contrary, it is pressed back to its hiding places, and the miner advances with safety.

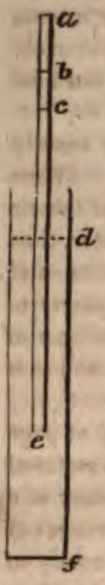
We see from this that any reservoir or vessel containing air would itself answer as a barometer if the only opening to it were through a long tubular neck, containing a close-sliding plug, for then according to the weight and pressure of the external air the density of that in the cavity would vary, and all changes would be marked by the position of the moveable plug. A beautiful barometer has really been made on this principle by using a vessel with a long slender neck of glass, in which a globule of mercury is the moveable plug.

The state of the atmosphere, as to weight, differs so much at different times in the same situation, as to produce a range of about three inches in the height of the mercurial barometer; that is to say, from twenty-eight to thirty-one inches. On the occasion of the great Lisbon earthquake, however, the mercury fell so far in the barometer, even in Britain, as to disappear from that portion at the top usually left uncovered for observation. The uncovered part of the barometer is commonly of five or six inches in length, with a divided scale attached to it, on which the figures 28, 29, &c. indicate the number of inches from the surface of the mercury at the bottom to the respective divisions:—on the lower part of the scale the words *wind* and *rain* are generally written, meaning that when the mercury sinks to them, wind and rain are to be expected and on the upper part, *dry* and *fine* appear, for a corresponding reason: but we have to recollect that it is not the absolute height of the mercury which indicates the existing or coming weather, but the recent change in its height;—a falling barometer usually telling of wind and rain; a rising one of serene and dry weather.

The barometer answers another important purpose, besides that of a *weather-glass*—in enabling us to ascertain readily the height of mountains, or of any situation to which it can be carried.

As the mercurial column in the barometer is always an exact indication of the pressure produced by the mass of air above its level, being indeed, as explained in the foregoing paragraphs, of equal weight with a column of the air of equal base with itself, and reaching from it to the top of the atmosphere;—the mercury must fall when the instrument is carried from any lower to any higher situation, and the degree of falling must always tell exactly how much air has been left below. For instance, if thirty inches barometrical height mark the whole atmospheric pressure at the surface of the ocean, and if the instrument be found, when carried to some other situation, to stand at only twenty inches, it proves that one-third of the atmosphere exists below the level of the new situation. If our atmospheric ocean were of as uniform density all the way up as our watery oceans, a certain weight of air thus left behind in ascending would mark every where a change of level nearly equal, and the ascertaining any height by the barometer would become one of the most simple of calculations:—the air at the surface of the earth being about twelve thousand times lighter than its bulk of mercury, an inch rise or fall of the barometer would mark every where a rise or fall in the atmosphere of twelve thousand inches or one thousand feet. But owing to the elasticity of air, which causes it to increase in volume as it escapes from pressure, the atmosphere is rarer in proportion as we ascend, so that to leave a given weight of it behind, the ascent must be greater, the higher the situation where the experiment is made: the rule therefore of one inch of mercury for a thousand feet, holds only for rough estimates near the surface of the earth. The precise calculation, however, for any case, is still very easy; and a good barometer, with a thermometer attached, and with tables, or an algebraical formula founded on observation of all the influencing circumstances, enbles us to ascertain elevations much more easily, and in many cases more correctly, than by trigonometrical survey.

The weight of the whole atmospherical ocean surrounding the earth being equal to that of a watery ocean of thirty-four feet deep, or of a covering of mercury of thirty inches; and the air found at the surface of the earth being eight hundred and forty times lighter than water, if the same density existed all the way up, the atmosphere would be 34 times 840, or about 28,000 feet high, which is equal to five miles and a half. On account of the greater rarity, however, in the superior regions, it really extends to a hight of nearly fifty miles. From the known laws of aerial elasticity, explained at page 287, we



of *b*. It is evident that on then closing the top of *a* in an air-tight manner, and lifting the tube, a column of mercury will remain in the tube, above the level of the external mercury at *d*, and will be acting as a piston pulling down from *b* with force proportioned to the height of the column. Then if the tube be lifted until such mercurial column *c d* be just half the length of the column in a common barometer, the air in the pores of the substance will be relieved from half of the atmospheric pressure, and will dilate to double bulk, and while half of the air will remain in the pores, the other half will issue forth and will occupy the space *b c*, between the surface of the mercury and the partition at *b*. This space *b c*, therefore, will be exactly equal to the amount of the pores or interstices; and as it may be measured and compared with the whole space *a b*, its ascertained magnitude will solve the problem. Mr. Leslie has found in this way that charcoal, which is usually said to be only half as heavy as its bulk of water, is really formed of matter nearly four times as heavy; proving, in a new way, the identity of charcoal and diamond: and he has found light pumice-stone to consists of matter heavier than granite or marble. His very ingenious thought may lead ultimately to many useful results, and the contrivance merits consideration here, as exhibiting under a new and interesting aspect the rational of barometric action and the elasticity of air.

Atmospheric pressure determining the liquid or aeriform state of certain substances. (See the analysis, page 282.)

It has already been stated that the gases or substances usually in the aeriform state, may be reduced to the liquid, or even solid form by simple pressure, and abstraction of the heat which was combined with them in the aeriform state. Common air, carbonic acid, the common coal gas, &c. have been treated in this way. Now it becomes an interesting question whether many other substances at present known as liquids on the face of the earth, where they are bearing the pressure of the atmosphere, might not appear as airs if that pressure did not exist.

On investigating this subject by experiment, we accordingly find, that *ether, alcohol* or *ardent spirits, volatile oils,* &c., and even *water* itself, are only known to us here as liquids, because their particles are kept together by the weight and pressure of a superincumbent atmosphere. Any of these substances, relieved by art from such pressure, immediately becomes an air or gas, just as a common gas, which has been kept in the state of liquid by any great pressure, becomes air again on being relieved.

In our first chapter we explained the dependance of the three forms which any body may assume, *viz.* of solid, liquid, or air, on the quantity of heat diffused among the particles: we now see however that, to understand the subject completely, we must consider also the effect of accidental pressure; for, while heat is the power separating the atoms in the changes mentioned, it has to overcome both the mutual attraction of the atoms and the additional force of the atmosphere pressing them together. The combined influence of these forces is fully displayed in the two phenomena called *boiling* and *evaporation,* which exhibit the progress of the change of a liquid into an aeriform fluid:—phenomena which we now proceed to examine.

Boiling.—If water be placed in a suitable vessel over a common fire, or over the flame of a lamp, it is gradually heated to a certain degree; and then small bubbles of aeriform matter (water, *viz.* in the state called steam) are seen forming at the bottom of the vessel, and successively rising to the surface, where they disappear by mixing with the atmosphere; and the operation being continued, the quantity of water diminishes with every bubble, until the whole vanishes under the new form of air.

This change takes place in water, under common circumstances, at the degree of heat marked 212° on Fahrenheit's thermometer; at which therefore, the repulsive powera mong the particles is just sufficient to overcome both their natural attraction, and the compressing force of the atmosphere of fifteen pounds on the inch. But a less degree of heat suffices if the pressure of the atmosphere be lessened or removed; and a greater degree is required if pressure be increased.—Water on the top of Mont Blanc boils at 180°, because relieved from the pressure of the air that is below the level of the mountain's summit; and at all intermediate heights in descending to the level of the sea, or still farther to the bottom of mines below that level, there is a corresponding increase of the boiling temperature.—So exactly is this the case, that we now find it to be a good method of ascertaining the heights of places, merely to observe the heat of boiling water at them.—In a boiler the water near the bottom is the hottest, because it is bearing an additional pressure proportioned to the depth, and does not therefore give out the steam which it would part with if a little higher up. In very large and deep boilers, therefore, such as are used in great porter breweries, the liquor is much more heated than it can be in smaller vessels;—a circumstance which probably has an influence on its ultimate quality.

While water under common atmospheric pressure, or when the barometer stands at thirty inches, boils at 212°, other substances, with other relations to heat, have their *boiling points* higher or lower:—ether, for instance, at 98°; spirit or alcohol at 174°; fish-oil and tallow at about 600°; mercury at 650°.

It is in consequence of the different temperatures at which the particles of different substances acquire repulsion enough to rise against the atmospheric resistance, that the chemist is enabled to perform the operation called *distilling*. If a mixture of spirits and water, for instance, be heated up to 180°, the spirit will pass off in the aeriform state, leaving the water behind, and may be caught apart and condensed in any fit receiver. Distillation is the best means we possess of separating many substances from each other: as spirit from wine or other fermented liquor,—various acids from water,—water itself from its common impurities,—mercury from gold which it has been used to dissolve from among the rubbish of a mine or river-bottom.

We must call to mind here what was mentioned in a former part of the work, that a large quantity of heat combines with every substance during its change of form from solid to liquid, or from liquid to air; which quantity, from not remaining sensible to the thermometer, has received the name of *latent* or *concealed heat*. The same is given out again in the contrary change. In the conversion of water into steam, the heat which thus disappears is about 1,000 degrees, or six times as much as is required to raise the cold water to the boiling point: this is proved by the time and fuel expended in boiling any quantity to dryness, and by the fact that a pint of water in the form of steam will combine instantly with six pints of cold water, raising the whole to boiling heat.

But for the fact of latent heat, the conversion of a liquid into air would not be the gradual process of boiling which we now see, but a sudden and terrible explosion: for when any quantity of water were raised to the boiling heat, one degree more would be sufficient to convert the whole into steam But for the same reason, the thawing of winter snow would always be a sudden and frightful inundation. On the other hand, if water in freezing had not to give out again its latent heat, after any quantity were once cooled down to the freezing point, the abstraction of one degree more would convert the whole into a solid mass.—Thus, then, effecting most important purposes in nature and art, all changes from solid to liquid, and from liquid to air, and the converse changes, are very gradual.

If a little heat be abstracted from steam, a part of the steam proportioned to the abstraction is immediately condensed into water. What is called steam in common language—as the vapour issuing from a boiling kettle or tea-urn—is not truly *steam*, but small globules of water already condensed by the cold air and mixed with it. Steam is as dry and invisible as air itself; but the instant that it comes in contact with air colder than 212°, it becomes water; and the exceedingly small particles uniformly scattered, exhibit the appearance so familiar to us.

The fact of *latent heat*, obvious as it appears when now stated, has been known but of late. The discovery of it led to those improvements of the steam-engine, which have since had such an effect upon the state of the arts of life. Dr. Black, of Edinburgh, and James Watt, of Glasgow, are the two names honoured by connexion with the discovery and its consequences.

By means of the exhausting air-pump on one hand, and of the condensing syringe on the other, all the above-mentioned facts, depending on the atmospheric pressure, and its increase or diminution, may be strikingly shown.

Thus to exhibit the effect of diminished pressure, water which is not heated by several degrees to the boiling point of ordinary low situations, but which would be boiling at the top of Mont Blanc, is caused to boil instantly by placing it under the receiver of an air-pump, and making a few strokes of the piston; if the exhaustion be rendered complete, the water will boil, even when less warm by 20° than the blood of animals; and at degrees of temperature still much lower, it will rapidly assume the form of air, although without exhibiting the violent agitation of boiling. Other liquids, as spirits, ether, &c., from requiring inferior degrees of heat to separate their particles to aeriform distances, boil under the receiver of an air-pump at very low temperatures; ether, for instance, when as cold as freezing water.

On the other hand, to exhibit the effect of increased pressure, if we confine the particles of a liquid still more than by a common atmospheric or equivalent weight, degrees of heat higher than the common boiling point will be required to separate them. In a diving-bell at sixty-eight feet under the surface, the boiling point of water is 272° instead of 212°, and at any other depth it is higher than 212° in proportion to the depth. At the surface of the earth, if we heat water in a close vessel into which we have forced air so as to press 30 pounds on the inch instead of 15, as the atmosphere does; or from which we prevent the steam from escaping until it has acquired the force of a double atmosphere,—before making the liquid boil we shall have to raise the heat, in a corresponding proportion beyond 212°. Under a very strong pressure, water may be rendered almost red-hot, but the force with which its particles are then tending to separate is almost that of inflamed gunpowder. Even then, however, if a gradual issue were allowed, only a certain quantity of the water would absorb and render latent the existing excess of heat above 212° and would become common steam, leaving behind a considerable portion as boiling water of the ordinary temperature.

The fact that liquids are driven off, or made to boil at lower degrees of heat when the atmospheric pressure is lessened or removed, has recently been applied to some very useful purposes.

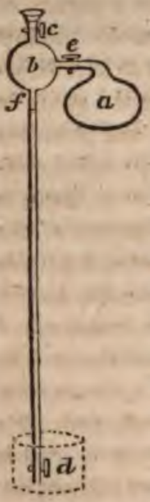
The process for refining sugar is to desolve impure sugar in water, and after clarifying the solution, to boil off or evaporate the water again, that the dry crystallized mass may remain. Formerly this evaporation was performed under the atmospheric pressure, and a heat of 218° or 220° was required to make the syrup boil; by which degree of heat, however, a portion of the sugar was discoloured and spoiled, and the whole product was deteriorated. The valuable thought occurred to Mr. Howard, that the water might be dissipated by boiling the syrup in a vacuum or place from which air was excluded, and therefore at a low temperature. This was done accordingly; and the saving of sugar and the improvement of quality were such, as to make the patent right, which secured the emoluments of the process to him and other parties, worth many thousand pounds a year. The syrup, during this process, is not more heated than it would be in a vessel merely exposed to a summer sun.

In the preparation of many medicinal substances, the process of boiling *in vacuo* is equally important. Many extracts from vegetables have their virtues impaired, or even destroyed, by a heat of 212°; but when the water used in making the extract is driven off *in vacuo*, the temperature need never be higher than blood-heat, and all the activity of the fresh plant remains in the extract.

In the same manner, in the process of distillation,—which is merely the receiving and condensing again in appropriate vessels the aeriform matter raised by heat from any mass,—substances which are changed and injured by an elevated temperature, may be obtained of admirable quality by carrying on the operation in a vacuum. The essential oils of lavender, peppermint, &c. never had the natural flavour and virtues of the plants until within the last few years, since this plan has been adopted.

The influence on the human system of vegetable medicines thus obtained, is so different from that of the old preparations, that the practitioner requires carefully to advert to the circumstance.

The apparatus for evaporating and distilling *in vacuo* consists of vessels strong enough to bear, when quite empty, the external atmospheric pressure, and therefore generally of arched form. The vacuum is produced and maintained by air-pumps driven by a steam-engine or otherwise; or by the direct admission of steam, which after expelling the air is condensed into water.



The author proposes a very simple contrivance to answer the purpose of such air-pumps and steam-engines or apparatus, and which in many instances therefore may be preferable. It is merely to establish a communication between a close boiler as *a*, and the vacuum at the top of a water barometer, as *b*. The strong vessel *b* forming the top of the barometer, and thirty-six feet of tube below, reaching to *d*, are first filled with water through a cock *c* at the top; this cock being then shut, and another cock *d* at the bottom being opened, the water will sink down out of the vessel, *b*, until the column in the tube be only thirty-four feet high, as at *f*, that being the height which the atmosphere will support. On then opening a communication between the boiler *a* and the vacuum in *b*, the operation will go on as desired, and the steam rising from *a* may be condensed in *b* by a little stream of cold water allowed constantly to run through from above. This water it is evident, would always pass downwards to the column below, without filling up or impairing the vacuum. If air should find ad-
]

mittance in any way, the perfect vacuum could easily be reproduced as at first; and it might be convenient to have two similar vessels like *b*, of which one could be emptied of air while the other were in action. The author planned this as a simple apparatus for the preparation of medicinal extracts; and it appears also particularly well suited for the manufacturing of sugar in the colonies, where air-pumps and nice machinery can with difficulty be either obtained or managed. On many sugar estates there is a fall of water, which would supply the barometer without the trouble of pumping. The tube *d c* need not be perpendicular, provided it be longer in proportion to its obliquity; and it may be very small. Some yards of common lead-pipe would answer.

When it was understood that, at common temperatures, water and many other liquids would be existing in the form of air, but for a pressure opposing the separation of the particles, it became of great importance in many of the arts, and for comprehending certain phenomena of nature, to ascertain, very exactly, with respect to such liquids, the degrees of expansive force belonging to them at different degrees of temperatures. The subject, as regards water, has been investigated with great care, and the following table shows part of the results. The left-hand column marks temperatures from 32° of Fahrenheit's thermometer, or the freezing point of water, to 290°; and the right-hand column marks the corresponding degrees of force with which the water tends to expand into the state of steam,—and therefore also the force and density of the steam which must be collected in any vessel above the water to restrain the change. One ounce and a half per square inch, is the force of steam rising from freezing water, that is to say, the force with which freezing water seeks to dilate; and sixty pounds per inch is the force of water heated to 290°.

At 32° force of steam is	1½ oz. per inch.
50	2¾ oz.
100	13 oz.
150	4 lbs.

At 180° force of steam is	7½ lbs. per inch.
212	15 lbs.
250	30 lbs.
272	45 lbs.
290	60 lbs.

In this table we have to remark how much more rapidly the tendency to form steam increases than the temperature of the water; for a rise of eighteen degrees, *viz.* from 32° to 50°, at the beginning of the scale, only increases the dilating force *one ounce and a quarter* on the inch, while an equal rise at the top of the scale *viz.* from 272° to 290°, increases it *fifteen pounds.* This circumstance, imperfectly understood, has led to many vain schemes for improving the *steam-engine.* Now the truth is, that *high-pressure steam* is merely *condensed steam*, as *high-pressure air* is *condensed air;* in other words, the density of steam is greater always exactly as its force is greater; and the heat absorbed in its formation being proportioned to the density, the force and the cost in caloric or fuel have the same relation to each other, at whatever density the steam is put to use. In one pint of steam at 290°, having an elastic force of sixty pounds on the inch, there is very nearly four times as much water and four times as much latent heat as in one pint of steam at 212°, which has a force of fifteen pounds on the inch. It does not accord with the plan of this work to enter into the minute details of this subject, but they may be found in Dr. Ure's excellent Dictionary of Chemistry under the title CALORIC.

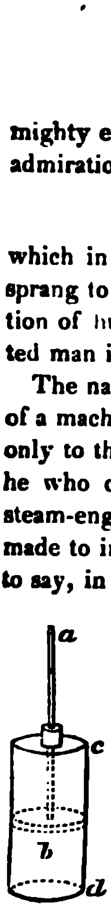
Seeing the rapid increase of the expansive force in the above table, we have the explanation of the terrible effects occasionally produced by confined water when overheated. A boiler of any kind, if completely closed and having no safety valve, will explode as if charged with gunpowder. Unhappily the instances are too numerous where the incautious or ignorant use of steam has produced explosions, which have shattered buildings and destroyed whole neighbourhoods.

To this part of our subject belongs the consideration of that mighty engine, which cannot now be mentioned without high admiration, *viz.*

The Steam-Engine,

which in the few years, since, from the genius of WATT, it sprang to its present state of perfection, has changed the direction of human industry, and may almost be said to have elevated man in the scale of existence.

The name of *steam-engine*, to most persons, brings the idea of a machine of the most complex nature, and hence intelligible only to those who will devote much time to the study of it; but he who can understand a common pump may understand a steam-engine. It is in fact only a pump in which the fluid is made to impel the piston instead of being impelled by it, that is to say, in which the fluid acts as the *power* instead of being the *resistance*. It may be described simply as a strong barrel or cylinder *c d*, with a closely fitting piston in it, as at *b*, which is driven up and down by steam admitted alternately above and below from a suitable boiler; while the end of the piston rod *a*, at which the whole force may be considered as concentrated, is connected in any convenient way with the work that is to be performed. The power of the engine is of course proportioned to the size or area of the piston, on which the steam acts with a force according to the density, of from 15 to 100 or more pounds to each square inch. In some of the Cornish mines there are cylinders and pistons of more than ninety inches in diameter, on which the pressure of the steam equals the effort of six hundred horses.



Sometimes the piston-rod of a steam-engine is made to act upon one end of a great vibrating beam, while at the other end, immense water-pumps are connected, which cause almost a river to gush up from the bowels of the earth. At other times acting on a crank, it is made to turn complicated machinery; and one engine, stretching long arms over a great barrack or manufactory, keeps thousands of spinning-wheels in motion on one side, desired speed, the balls fly more apart, and are made to affect the steam valve so as to narrow the passage; and on the contrary, when it turns more slowly than is desired, they collapse, and by so doing open the valve wider.—7th. The *supply of water* to the boiler is regulated by a *float* on the surface of the water contained in the boiler, which on descending to a certain point, by reason of the consumption of water, opens a valve to admit more.—8th. There is a *safety valve* in the boiler, *viz.* a well fitted stopper, loaded so as to open before danger can arise from the overheating of the water. 9th. The *rapidity of the combustion*, or force of the fire, may be exactly regulated by the state of the boiler and the wants of the machine, thus:—there is a large open tube (not represented here) rising from near the bottom of the boiler, through its top to a height of several feet, and when the water in the boiler is too hot, and the steam therefore too strong, part of the water is pressed up into this tube, and by the agency of a float which rests on its surface, it shuts the chimney-valve or *damper:* the draught is then diminished and the fuel saved, until a brisker fire is again required. —10th. In this figure, *a i g* marks the place of the *great beam*, turning on an axis at *i*, and through which the force of the piston is usually conveyed to the remote machinery. When the object is to raise water, the pump-rods are simply connected with the end *g* of the beam, but when any rotatory motion is wanted, the end *g* is made to turn—11th. a *crank l n* by the rod *g l;* and uniformity of motion is obtained by the influence of—12th. the great *fly-wheel m* fixed to the axis of the crank.

The smallest and simplest steam-engine, and therefore the cheapest, is that called the *high pressure engine.* In it steam is used of great density, and consequently of great force, as of 40 or 50 *lbs.* or more to the inch; and while the fresh steam is pressing on one side of the piston, the steam which has already worked is merely allowed to escape, or rather is driven out to the air, from the other side. The atmospheric resistance to the issue of the steam diminishes the working force of the piston just 15 *lbs.* per inch. The simplicity of this form of engine recommends it, but the danger of a large boiler of over-heated water, like inflamed gunpowder, seeking to escape, has by numberless fatal accidents been proved so great, that the use of such an engine is limited to certain situations:—notwithstanding all the ingenious securities recently contrived against the danger, it is not employed in a single English passage-vessel.

In the low-pressure engine, the steam is used generally of force not exceeding 20*lbs.* on the inch, which force being 5*lbs.* only more than the atmospheric pressure, is insufficient to burst a common boiler or to do mischief:* but as the interior of the low-pressure engine is kept in a state of vacuum, except where the steam is acting the whole pressure of 20*lbs.* is made available, and the engine has the same power, if of equal size, as a high-pressure engine working with steam of 35*lbs.* on the inch. The required vacuum is preserved by means of a separate vessel or box c, called the condenser, into which cold water is constantly running to condense the steam, and is then pumped out again with the condensed steam, and with any little air that may have entered by a pump represented at *k* in the figure. Steam on coming into contact with a cold body is condensed with the rapidity of an explosion; and therefore the instant that opened valves make a communication between the cold condenser and any part of the engine containing steam, this rushes to the condenser and becomes water, leaving a vacuum behind. The great merit of Mr. Watt was in the contrivance of this separate condenser, for, until his time, cold water had always been thrown directly into the working cylinder, and cooled it so much, that twice or thrice its fill of steam was destroyed at each stroke to warm it again before it could work. This single change saved three-fourths of the fuel formerly expended.

---

* Experience would seem to prove that the safety of the low-pressure engine is here over rated and the danger from the high pressure exaggerated. But to explain this, it would be necessary to enter more profoundly into the subject, than would comport with the character of this work. It is right however to mention, that when accidents have occurred, with either of there forms of engine, it appears always to have been owing to carelessness. AM. ED.

Before Watt's day, the only steam-engine in use was a rude *single-stroke engine*, as it was called, in which steam pushed the piston up, and being then condensed so as to leave a vacuum in the cylinder, the pressure of the atmosphere pushed the piston down to do its work: on this last account the engine was also called an *atmospheric engine*. It was used almost solely for pumping water, but it wasted so much fuel, from the cause mentioned in the last paragraph, that the expense was not much less than that of horses.

In the atmospheric engine, the steam which lifted the piston against the atmospheric pressure, required to be at least as strong as that pressure, to the very end of the stroke. Another of Watt's great improvements was, his excluding altogether the air from his machine, by doing which he not only avoided the cooling effect of the air, but was at liberty to shut off the steam, as it expressed, or to stop the supply for each stroke, before the cylinder was full, and then to make the further expansion of the quantity admitted impel the piston to the end of the stroke. This principle of causing the mere expansion of steam to do work was afterwards carried to a great extent by Messrs. Hornblower, Woolfe, and others, who constructed engines with two barrels, in the first and smaller of which, the steam was made to act in its dense or strong state, and when it had finished a stroke there, instead of being sent useless to the condenser, it was admitted to a larger piston, which it moved by its continued expansion alone: the same steam thus doing double work or more. All the advantages of the two cylinders, however, are obtainable from the single cylinder as now used in most of the Cornish mines. Steam of about 40*lbs.* pressure on the inch is admitted to the cylinder, until the piston is driven one-third of its way, and the valve being then shut, the same steam is left to finish the stroke by its expansion alone. The pressure of the expanding steam gradually diminishes, it is true, in proportion as the volume increases; but in pumping water there is a great saving of time, from having the power more intense at the beginning of the stroke, when the vast mass of water and machinery has first to be put into motion.

It might be supposed that high-pressure engines without condensers would be wasteful, because in them the steam which has acted, must be driven out of the cylinder against the powerful resistance of the atmosphere, while in the low-pressure engine it has instant access to the condenser, and leaves effective the whole pressure of the fresh steam on the opposite side of the piston. But as in the low-pressure engine, nearly half the power of the steam is expended in overcoming the friction and other impediments of the numerous parts; while in that of high-pressure, the parts are so much fewer, and the piston is so much smaller in proportion to the force acting upon it, that the loss from friction is often less than a fourth, or even a sixth of the steam-power,—although the resistance of the air is to be overcome by the high-pressure engine, still there is often a saving on the whole. The saving becomes very considerable if the steam be allowed to act by its expansion also, as described in the last paragraph.

From misapprehension of the law of increase of force by increase of heat in water, explained by the *table* at *page 329*, some exceedingly false conclusions have been drawn, and acted upon at great expense—as lately by Mr. Perkins, in attempts to make engines to work with an excessively high pressure. Besides making the error now alluded to and others, Mr. Perkins also neglected the fact that we possess no material for cylinders and pistons strong enough to bear the contemplated pressure and friction even for a moderate time. Perhaps better proof could not be adduced of the absurdities into which even highly ingenious men may fall, when ignorant of those general truths of nature on which all branches of art are founded, than the history of supposed inventions and improvements connected with the steam-engine.

The fertile genius of James Watt did not stop at the accomplishment of the two or three important particulars described above, but throughout the whole detail of the component parts, and of the various applications of the engine, he contrived miracles of simplicity and usefulness. We should exceed the prescribed bounds of this work by entering more minutely into the subject; but we may remark that, in the present perfect state of the engine, it appears a thing almost endowed with intelligence. It regulates with perfect accuracy and uniformity the *number of its strokes* in a given time, and *counts* or *records* them moreover, to tell how much work it has done, as a clock records the beats of its pendulum:—it regulates the *quantity of steam* admitted to work;—the *briskness of the fire*;—the *supply of water* to the boiler;—the *supply of coals* to the fire;—it *opens and shuts its valves* with absolute precision as to time and manner;—it *oils its joints*—it *takes out any air* which may accidentally enter into parts that should be vacuous;—and when any thing goes wrong which it cannot of itself rectify, it *warns its attendants* by ringing a bell;—yet with all these talents and qualities, and even when possessing the power of six hundred horses, it is obedient to the hand of a child;—its aliment is coal, wood, charcoal, or other combustible;—it consumes none while idle;—it never tires, and wants no sleep;—it is not subject to malady when originally well made; and only refuses to work when worn out with age;—it is equally active in all climates, and will do work of any kind;—it is a water pumper, a miner, a sailor, a cotten-spinner, a weaver, a blacksmith, a miller, &c. &c.: and a small engine in the character of a *steam poney* may be seen dragging after it on a rail-road a hundred tons of merchandize, or a regiment of soldiers, with greater speed than that of our fleetest coaches. It is the king of machines, and a permanent realization of the *Genii* of Eastern fable, whose supernatural powers were occasionally at the command of man.

We need not wonder that the inventor of an engine having such qualities, should receive the highest honours which his fellow-men could bestow. In November 1825, a public meeting was called, to vote a monument to WATT, then not long deceased; and the most distinguished men of the empire, of all parties, philosophers and statesmen, met to vie with each other in speaking his praise. Perhaps a series of such eloquent discourses have rarely been pronounced at one time; and perhaps in the progress of the arts of civilization there can rarely be offered such motive and occasion. The common voice of that distinguished assembly scarcely exaggerated, when attributing to WATT's genius and perseverance that great increase of our national commerce and riches, which had enabled free Britain, single-handed, at an extraordinary crisis of human affairs, to contend with Europe combined against her, and at last to triumph, so as to secure her own happy destinies, and probably much to influence those of the human race.

As science and the twin sister art are making constant advances, who shall say that even the steam-engine, perfect as we have described it, is the limit to human discovery of mighty yet obedient force? It is true that the nature of steam, and the laws of its formation and action, are now so well understood, that the intelligent engineer no more hopes for great improvement in steam-engines, than he hopes for it in the mode of using a waterfall to turn a mill; but still there are kindred regions of nature left almost unexplored. We shall make a remark on this subject in our next chapter, while considering the nature of *heat.*

The explosion of gun-powder and of all fulminating mixtures bears so strong an analogy to the phenomenon of the formation of steam, that the mind may advantageously contemplate the subject in this place.

The ingredients of which gunpowder is formed are chiefly substances which when separate, exist, at any common temperature in the form of air; and the combustion sets them loose, with a production of intense heat, causing an increase of volume which is instantaneous, and almost irresistible. By experiment, and mathematical deduction, it appears that the exploding particles begins to separate from each other with a velocity as if ten thousand volumes of air had been condensed into one: and this explains the corresponding force and swiftness with which a bullet is propelled.

All the fulminating metals are chiefly combinations of the like substances with the metals; and the ingredients are held together by so slight a tie, that a little friction or elevation of temperature disunites them to produce the explosion.

The escape of condensed air from the chamber of an air-gun, is a species of explosion; but is very gentle compared with the shock of discharged gunpowder.

It has lately been shown that a gun-barrel may be connected with a high-pressure steam-boiler, in the same manner as with a chamber of condensed air, and as the steam can be supplied as long as water remains in the boiler, if bullets be allowed to fall into the barrel fast enough, a hundred or more may be thrown out every minute, with the same force and precision as if each issued from a common piece of artillery. The rapid succession resembles the issue of water from a jet pipe; and if such an engine could be used in a field of battle, its barrel of death, made to point gradually along a line of men, would mow them down like corn-stalks before the scythe—none could escape. The horrible idea and proposal have been excused by saying, that to prove the possibility of such carnage must have the effect of putting an end to war altogether.

The invention of gunpowder, with the consequent change of military tactics, because it gave to a handful of men possessing it, the mastery over thousands who had it not, was hailed by the philosophers of the day as a certain security against the relapse of civilized mankind into such a state of barbarism as followed the irruption into Europe of the Goths and Vandals:—none but highly instructed and disciplined armies could then enter a European kingdom. This consideration, however, has lost its interest, since from the invention of printing and other changes in society, still better and more humane securities have been obtained.

Besides the interesting instances now cited of the pressure of the atmosphere determining whether certain substances shall or shall not have the form of air, there are others that deserve mention, where the effect is modified by chemical combination of substances.

The pressure of the atmosphere at the surface of the earth keeps a certain quantity of air in combination with water, so as to form part of the liquid mass. This air re-appears at once on taking off the pressure. If we place a glass of water under the receiver of an air-pump and then exhaust, the glass is soon filled with bubbles of air, seen adhering all around on the sides, or rising through the water. This admixture of air in water is necessary to the life of fishes. It is driven off by boiling, and hence the vapid taste of water that has been boiled.

In the making of beer, wine, and other fermented liquors, there is a large quantity of the substance called carbonic acid formed during the fermentation. Much of it flies off in its usual form of gas, but, because of the pressure of the atmosphere much still remains in union with the liquid. On removing this pressure suddenly, the liquid appears almost to boil, as when a glass of warm beer is placed under the air pump vacuum.

A degree of pressure still greater than that of the atmosphere, keeps a proportionally larger quantity of this carbonic acid in liquid combination; as in bottled porter or sparkling champaigne before the cork is drawn; but as soon as the compression maintained by the cork is removed, the gas escapes, causing the thin champaigne to sparkle, and the more viscid beer, which retains the little bubbles as they rise, to be covered with froth. After the sparkling or frothing have ceased under the atmospheric pressure,—by placing the glass in the air-pump receiver the phenomenon may be renewed.

Carbonic acid so readily become liquid when its attraction for water assists the compression, that enough of it may be united with water to make a pint become a pint and a half. The soda water, or aerated water, now so generally used in Europe as drink in warm weather, is water with several times its bulk of carbonic acid forced into it by pressure; and a part of this is seen escaping always at the instant of the confining cork being drawn.

Carbonic acid forms one-fourth of the substance of marble or lime-stone. When another stronger acid, as vinegar or sulphuric acid, is poured upon marble, it dispossesses the carbonic acid, and unites itself with the pure lime. The carbonic acid in rising constitutes the effervescence which then appears. Carbonic acid for the manufacture of the common soda water and other aerated drinks is obtained in this way.

Many mineral waters contain carbonic acid, which remains in tranquil combination while the water is bearing a certain pressure under-ground, but which in part escapes as soon as only the atmospheric pressure remains: such waters are called sparkling waters.

The reason that champaigne and the aerated waters are so cool when first decanted is, that the carbonic acid, in assuming its gaseous form, absorbs, as latent heat, a large proportion of the heat which was previously existing in the liquid.

The atmospheric pressure, by causing different densities in the air, at different heights above the level of the sea, causes corresponding differences of temperature.

The explanation of this is simple. If a gallon of air at the surface of the earth contain a certain quantity of heat, this must be diffused equally through the space of the gallon; but if the air be then compressed into one-tenth of the bulk, there will be ten times as much heat in that tenth as there was before; and the increase will affect the thermometer to an extent modified by other circumstances explained in a future part of this work. In like manner, if by taking off pressure the gallon be made to dilate to ten gallons, the heat will be in the same degree diffused, and any one part will be colder than before. It is known that air may be so much compressed under the piston of a close syringe, that the heat in it similarly concentrated, becomes intense enough to inflame tinder attached to the bottom of the piston:—this means is in common use for obtaining an instantaneous light, and is called the *match-syringe.*

Now, for the reason here explained, the air near the surface of the earth, forming the bottom of the atmosphere, because condensed by the weight of the air above it, is much warmer than if it were suddenly carried higher up to where, from the pressure being less, it would be more expanded or thin. In many cases the height of mountains may be estimated by the difference of temperature observed at the bottom and at the top.

While a thermometer stands at 60° at the bottom of St. Paul's Cathedral in London, another marks only 58° at the top of the dome; and in the lofty ascent of a balloon, the thermometer soon falls to the freezing point and below it, while the aeronaut feels a cold almost insupportable.

In every part of the earth at a certain elevation in the atmosphere, different according to the latitude or proximity to the equator, the thermometer never rises above the freezing point, —and this limit is called the line or level of perpetual congelation. In Norway it is at five thousand feet above the level of the sea; in Switzerland at six thousand five hundred; in Spain and Italy at seven thousand; farther south, at Teneriffe, at nine thousand; directly under the sun, as in Central Africa and among the Andes in America, it is about fourteen thousand. We see therefore why the snow-capt mountains are not the tenants only of high northern and southern latitudes. It is this effect of elevation which renders many of the tropical regions of the earth not only tolerable abodes for man, but as suitable as any on earth;—although the ancient philosophers of Europe accounted them, by reason of the great heat, an everlasting barrier as regarded man, between the northern and southern hemispheres. Much of the tropical land of America is so raised, that it rivals as to agreeable temperature even a European climate; while the lightness and purity of air, and the brightness of the sun, add delightfully to its charms. The vast expanse of table-land forming the empire of Mexico is of this kind, enjoying the immediate proximity of the sun, and yet, by its elevation of seven thousand feet above the level of the ocean, possessing the most healthful freshness. The land in many parts has the fertility of a cultivated garden, and can produce naturally most of the treasures which vegetation offers over the diversified face of the world. The plains of Colombia, in South America, and indeed all along the ridge of the Andes, are similarly circumstanced. The contrast is very striking, after sailing a thousand miles up the level river Magdalena, in a heat scarcely equalled on the plains of India, all at once to climb to the table-land above, where *Sante Fé de Bogota*, the capital of the republic, is seen smiling over interminable plains, that bear the livery of the fairest fields of Europe!

Persons not understanding the law which we are now illustrating, will express surprise that wind or air blowing down upon them from a snow-clad mountain should still be warm and temperate. The truth is, that there is just as much heat combined with an ounce of the air on the mountain top as in the valley, but above, the heat is diffused through a space perhaps twice as great as when below, and therefore is les sensible. It may be the same air which sweeps over a warm plain at the side of a mountain,—which then rises and freezes water on the summit:—and which in an hour after, or less, is playing among the flowers of another valley, as a warm and gentle breeze.

As the temperature in different parts of the atmosphere depends thus upon the rarity of the air, and therefore upon the height, the vegetable productions of each distinct region or elevation have a distinct character, while many other peculiarities of place and climate spring from the same source.

Because the atmospheric pressure determines the temperature of the air in different situations, as now explained, it has also a corresponding influence upon the state of aerial humidity, which is modified by the temperature.

It was explained at page 329, that water and other liquids under a vacuum rise in the form of air or vapour with force and in quantity having a strict relation to the temperature—heat being in fact the cause of their rising; and the table at page 329 exhibits the force, and therefore the density of watery vapour corresponding to some certain temperatures. Now it is a remarkable circumstance, that vapour in the same quantity and of equal tension rises at a given temperature from any liquid, whether placed under the pressure of air, or under a vacuum; only through a space containing air it diffuses itself more slowly than if the air were not present. As regards the former case, it was for a long time supposed that the air dissolved the liquid as a liquid dissolves a salt: but it now appears that there is merely a mechanical mixture of the two. If the vapour, while rising from a liquid, has not a tension or elastic force equal to the pressure of the atmosphere, the process is tranquil, and is called *evaporation*, and it goes on only as the vapour can diffuse itself among the particles of the air, and therefore slowly in air perfectly quiescent, but quicker as the air is moving more, or as the density of the air is less. But when the vapour, owing to greater heat, is strong enough to overcome the atmospheric pressure of fifteen pounds per inch, the phenomenon of boiling arises as already described.

For the reason now explained, the air of our atmosphere contains diffused through it a large quantity of invisible aeriform water; and if no changes of temperature happened in the atmosphere, the quantity of water would soon reach a *maximum*, or would constantly be the greatest that the medium temperature of the earth could support; instead of this, however, from a variety of causes to be explained below, the local temperatures are ever fluctuating, and when lowered in situations where a maximum of watery vapour is present, part of this is instantly reduced to the state of water again, and appears in the form of *mist*, *rain*, *snow*, or *hail;* while to supply material for these phenomena, evaporation is going on wherever. over water, there is not a *maximum* of vapour in the air. These opposing operations of evaporation and condensation keep up that constant circulation of moisture which is the life of nature.

When a given quantity of water assumes the aeriform state, it contains the same quantity of latent heat in all cases, whether rising, for instance, from a boiling cauldron, or from the surface of a lake. Hence we see why evaporation is so cooling a process to any liquid or moistened solid from which it is arising; and as we have already shown that a rapid passing of dry air, or a vacuum, quickens evaporation, we now see why both of these conditions accelerate the cooling. Wet linen placed in a strong wind becomes dry almost immediately; a bottle of wine covered with a wet cloth and suspended in a current of air, as is practised in warm climates to prepare wine for the table, is quickly cooled; mats hung up around the walls of houses in India, and frequently wetted through the day, preserve a delightful freshness in the apartments. The rapidity of evaporation from water under the exhausted receiver of an air-pump, and particularly when some other substance which powerfully absorbs watery vapour is included in the receiver with it, is so rapid, and carries off the heat so quickly, that the mass of water freezes before much of it has been carried away. This process is used for making ice in India. Sprinkling water or vinegar over a hot sick-room cools and refreshes it; and watering the streets of a city moderates in them the intensity of summer heat. In warm climates water is cooled for drinking by being put into vessels so porous that the external surface is always moist, the vessels being then suspended in a current of air, or during a calm being made to vibrate in the manner of a pendulum.

It is because air is saturated with moisture, that is to say, having as much water diffused in it as can be supported in the invisible or aeriform state at the existing temperature,—lets fall a part on any reduction of the temperature, that air which, as a part of the atmosphere, has been heated by the sun during the day, and has received much moisture, lets it fall again during the night, and exhibits the night fogs of certain seasons, which float upon the surface of the earth, until again acted upon by the beams of the next morning's sun. Fog when condensed, by groups of the minute particles uniting, forms rain; and rain when cooled becomes snow or hail.

The quantity of dew which falls at night is much influenced by the quantity of moisture taken up by the atmosphere during heat of the day; and the immediate cause of the dew is, as was ingeniously proved by Dr. Wells some years ago, that the temperature of the objects on which it settles becomes lower during the night than can support the moisture in the surrounding atmosphere. There is a tendency in heat to diffuse itself uniformly among bodies, by a constant radiation from one to another, which is rapid in proportion to the differences of temperature, and it therefore soon reduces all to nearly the same degree. Now when there are clouds in the atmosphere at night, they receive the heat darted upwards from the bodies on the earth's surface, and they radiate heat back in return, becoming, as it were, a clothing to maintain the warmth of the earth beneath them, and on cloudy nights there is no dew,—but with a clear sky, the heat radiated upwards at night, darts into boundless space, and is lost altogether to the objects which emitted it. These objects, therefore, which during the day had the same, or even a higher temperature than the atmosphere around, now become colder, and the aeriform water which comes into contact with them is condensed, and forms a copious dew. This beautiful provision of nature supplies the necessary moisture to vegetables during seasons when rain is deficient. Dew on very cold objects freezes as it settles, and is then called *hoar frost.* A phenomenon which may class with dew is the perspiration, as it is vulgarly called, of massive walls and furniture, on the sudden occurrence of warm weather:—the wall or other object, from not having yet acquired the temperature of the surrounding air, condenses upon itself a part of the atmospheric moisture. For a similar reason a bottle of wine brought from a cold cellar into a room with company, is soon covered with thick moisture or dew.

Many instruments have been contrived, with the name of *hygrometers*, for indicating the quantity of water in the atmosphere. A prepared human hair is the essential part of one of the best of those formerly used: the lengthening or shortening of the hair, according to the quantity of moisture around it, being made to move an index like that of a wheel-barometer, to mark the degrees. This, however, and other common hygrometers, are only philosophical toys; but Mr. Daniel (see his excellent work, entitled Meteorological Essays) has lately given to the philosophical world a correct and simple instrument for the purpose. It depends on the principle explained above, that whenever a body in the atmosphere has a temperature below that at which the quantity of watery vapour in the air around can be maintained in the aeriform or invisible state, dew forms on the body. By cooling a bulb of glass until moisture begin visibly to settle upon it, and then noting the temperature on an enclosed thermometer, the proportion of water mixed with the air is discovered.

A great fall of the barometer indicates a diminished pressure in the atmosphere around, with a consequent dilatation of the air and fall of temperature, as explained a few pages back; and if the air at such a time hold a maximum of moisture, a part of this must become visible as fog or rain. Thus a fall of the barometer, a fall of temperature, and a fall of rain, often occur as associated phenomena.

Illustrating this by experiment, we find, that on the extraction of air from the receiver of an air-pump, a cloud or mist often appears in it after the first strokes of the piston:—the reason being that the still remaining air, because cooled by the rarefication, absorbs heat from the vapour in combination with it, and renders the water visible. The mist is then removed by the subsequent action of the machine, or is re-dissolved when the usual quantity of air is re-admitted.

We understand from this why rain happens so much more frequently among mountains than on extended plains. When air saturated with moisture approaches a mountain ridge to rise over it, for every foot that it rises, it escapes from a degree of the pressure which it bore while lower down, and in then dilating, it becomes colder, and lets fall part of its moisture. It is the rain periodically thus produced in mountainous regions which causes the extraordinary annual overflowing of many great rivers, as the Nile, the Ganges, &c.

Those who have visited the Cape of Good Hope, will recollect a striking phenomenon illustrative of our present subject, observed there when the wind blows from the south-east. Beyond the city, as viewed from the bay, there is a mountain of great elevation, called, from its extended flat summit, the Table Mountain. In general its rugged steeps are seen rising in a clear sky; but when the south-east wind blows, the whole summit becomes inveloped in a cloud of singular density and beauty. The inhabitants call the phenomenon the spreading of the table-cloth. The cloud does not appear to be at rest on the hill but to be constantly rolling onward from the south-east; yet, to the suprise of the beholder, it never descends, for the snowy wreaths seen falling over the precipice towards the town below, vanish completely before they reach it, while others are formed to replace them on the other side.—The reason of the phenomenon is, that the air constituting the wind from the south-east having passed over the vast southern ocean, comes charged with as much invisible moisture as its temperature can sustain. In rising up the side of the mountain it is rising in the atmosphere, and is therefore gradually escaping from a part of the former pressure; and on attaining the summit it has dilated so much, and has consequently become so much colder, that it lets go part of its moisture. This then appears as the cloud now described; but it no sooner falls over the edge of the mountain, and again descends in the atmosphere to where it is pressed, and condensed, and heated as before, than it is re-dissolved and disappears:—the magnificent apparition thus dwelling only on the mountain top.

When the elevation to which moisture is suddenly carried is very great, the fall of temperature is proportional, and the separating water becomes snow instead of rain. This phenomenon is remarkably illustrated by a *Hero's* fountain, used in one of the mines of Hungary; during the play of which, the air is so compressed, that on being released, it expands and cools enough to cause the moisture driven out with it to appear, even in summer, as a shower of snow.

The foregoing reasoning explains why along the sides of mountain ridges, clouds are generally seen floating at a certain height only, and therefore in horizontal strata. The water is separated from the air at a certain temperature, which is dependent on the height, as explained at page 342; and above that height the air appears too rare to give support to clouds. Very lofty summits are seen rising above the clouds altogether, and the admirer of nature who climbs towards them, may often contemplate the grand phenomena of the thunder storm far beneath his feet. Teneriffe soars so sublimely, that the distant sailor not unfrequently mistakes the line of clouds hanging around its sides for the white streak which elsewhere indicates the cliffs and waves of the sea-shore.

Fluid support or floating, in air. (*Read the analysis, page* 282.)

When it was explained, under "Hydrostatics," that any body immersed in a fluid is resisted or held up exactly with the force which would support a quantity of the fluid occupying the same space, and therefore that the body will sink or swim, according as it is heavier or lighter than its bulk of the fluid, the reasoning was as applicable to the case of a body immersed in an air as in a liquid.

We hence see why a body weighed in air appears lighter by the exact weight of its bulk of the air, than when weighed in an empty space or vacuum:—and why, for the same reason, the jocular question, whether a pound of lead or a pound of cork be the heavier, is not truly answered by saying that they are of equal weight: the cork is really the heavier, because when balanced in air, bulky cork is more supported than dense lead. A small weighing-beam, having pieces of cork and lead which equipoise in the air, attached to its opposite ends, if placed under the exhausted receiver of an air-pump, exhibits the cork preponderating.

As any liquid lighter than water, such as oil or spirits, on being set at liberty under the surface of water, will rise, while any heavier liquid, such as brine, syrup, or sulphuric acid, will sink; and in both cases with force proportioned to the difference of specific gravities—so we find, that in common air, a mass of hydrogen or hotter air ascends, because specifically lighter; while oxygen, carbonic acid gas, or colder air, descends, because specifically heavier.

A Balloon

is a thin light bag of varnished silk, generally shaped like a globe or egg, and filled with a fluid lighter than common air. It is made large enough that the difference between its weight and that of an equal bulk of common air, may enable it to carry aloft the material of which it is constructed, with the aeronauts, and their apparatus. It is in principle like a bladder of oil immersed in water. A globe of thirty-five feet diameter has a capacity of nearly twenty-two thousand cubic feet. This quantity of common air weighs about *sixteen* hundred pounds, and the same quantity of Hydrogen gas, of easily obtained purity, weighs only one-eighth as much, or *two* hundred pounds. Such a globe, therefore, being buoyed up, or supported in common air, with a force of sixteen hundred pounds, while, if filled with hydrogen, it only weighs two hundred, will carry up into the sky fourteen hundred pounds of material and load.

The first balloon was constructed by a man ignorant of what he was really effecting. Seeing the clouds float high in the atmosphere, he thought that if he could make a cloud, and enclose it in a bag, it might rise and carry him with it. Then erroneously deeming smoke and a cloud the same, he made a fire of green wood, and placed a great bag over it with the mouth downwards to receive the smoke. He soon had the joy to see the bag full, and ascending; but he understood not that the cause was the hot dilated air within, which, being lighter than the surrounding air, was buoyed up; while the visible part of the smoke, which chiefly engaged his attention, was really heavier than the air, and was an impediment to his wishes.

The *hot air or fire balloon* was afterwards better understood, and was used by aeronauts, until the more commodious and less dangerous modification, called the *inflammable air balloon*, or balloon of hydrogen gas, was substituted.

Since the modern introduction of gas lights, the *carburetted hydrogen* prepared for them is generally employed for filling balloons. It is considerably heavier than pure hydrogen, but is so much more readily obtained, that aeronauts prefer making a larger balloon to suit it, than a smaller one which obliges them to prepare the other. A thin paper bag, filled with the hot air rising from a large lamp, is a miniature *hot air or fire balloon;* and a common soap bubble filled with hydrogen, is a little *inflammable air balloon*, which mounts with great rapidity.

There are, perhaps, few occasions calculated more to surprise and delight, than when a balloon is first beheld sailing high in the bosom of the air, and lifting man to regions far beyond what the soaring eagle has ever reached: —and to the intrepid aeronaut himself, the scene of a world displayed beneath him is unquestionably the grandest which mortal eye has ever contemplated. Even wide spread London, the queen of the cities of the earth, and a little world within itself, when viewed from such an elevation in the sky, appears but as a dusky patch upon a map, where the far-famed Thames winds as a silvery line, and where the magnificent temples and palaces scattered around, appear but as darker points rising out of the general mass of buildings, in which a million and a half of human beings reside.

The first aeronautic expeditions astonished the world, and endless reveries passed through men's minds of important uses to which the new discovery might be applied; but more mature reflection, and now frequent trials have shown, that the balloon is interesting chiefly as a philosophical toy, and from having furnished philosophers with the opportunity of making some observations in elevated regions of the atmosphere. The French, under the Directory in 1796, attempted to use it as a military station, from which the position and motions of an enemy might be descried: but the plan was eventually abandoned. It has since been thought of as a means by which travellers might obtain information, while penatrating into unknown countries, like the almost interminable plains of *Australasia.* Although aeronauts, while aloft, have the power of making the balloon rise farther by throwing out part of the sand-ballast which they carry with them, or of making it descend by opening a valve at the top and allowing the hydrogen to escape, still they have no power of producing a lateral motion. The idea which yet [illegible] excites the minds of some projectors, that by wings or other means a balloon may be directed in the sky, nearly as a ship is directed on the sea, is not much more reasonable than to suppose that an insect, suspended to a huge block of wood, [illegible] at the rate of eight or ten miles an hour by a river torrent, should have power to stop or sail against the stream. A man in a balloon would generally have to resist or change a motion exceeding fifty miles in an hour.

A balloon which is only half full at the surface of the earth, becomes quite full when it has risen three miles and a half, because at that altitude, air from below doubles its volume on account of the diminished pressure. A balloon, therefore, if quite distended on first rising, must let air escape as it ascends, or it will burst: this is true also of the drum of the human ear under the same circumstances, and in a contrary way, under the opposite circumstances of descending in a diving-bell.

The downy seeds of plants seen floating about upon the wind in autumn, are not lighter than air, but have so much bulk and surface in proportion to their weight, that the friction upon them of the passing air is greater than their weight, and carries them along.

A sheet of paper, made in some degree to resemble a balloon, from having a little weight representing the car attached under it by threads from the angles, is often seen rising at a street corner, to the delight of the boy who watches it. Its rise depends upon eddy winds or currents which the corner produces.

The ascent of flame and smoke

in the atmosphere, affords other examples of a lighter fluid rising in a heavier; for both these are merely hotter air rising in the midst of colder.

The phenomenon of flame is produced when a burning substance contains some ingredient capable, on being heated, of assuming the form of air, and which ingredient on ascending, burns or combines with the oxygen of the atmosphere, with intensity of action sufficient to produce a white heat. It is because charcoal and coke have nothing in them thus volatile, that they burn without flame,—appearing like red-hot stones. The flame of a lamp or candle is merely the gas of the oil, wax, or tallow, allowed to burn as it is disengaged and rises. The same gas obtained by heating the oil, &c. in vessels which exclude the atmosphere, and prevent immediate combustion, is the common oil-gas used for illumination.

Smoke consists of all the dust and visible particles which are separated from the fuel without being burned, and are moreover light or minute enough to be carried aloft by the rising current of heated air: but all that is visible of smoke is really heavier than air, and soon falls again, as powdered chalk falls in water. In the receiver of an air-pump, where a candle has been extinguished by exhausting the air, the stream of smoke that continues to pour from the wick after the exhaustion, is seen to fall on the pump-plate, because there is no air to support it.

Chimneys quicken the ascent of hot air by keeping a large quantity of it together. A column of two feet high rises with twice as much force as a column of one foot, and so in proportion for all other lengths; just as two or more corks strung together, and immersed in water, tend upwards with more force than a single cork; or as a long spear of light wood, allowed to ascend perpendicularly from a great depth in water, acquires a velocity which makes it dart high above the surface, while a short piece under the same circumstances rises very slowly. In a chimney, one foot in height of the column of hot air, may be one ounce lighter than the same bulk of the external cold air; and if the chimney be one hundred feet high, the air or smoke in it is propelled upwards with a force of one hundred ounces. In all cases, therefore, the *draught*, as it is called, of a chimney, is proportioned to its length. The following facts are consequences of this truth.

In low cottages, and in the upper floors of houses, the annoyance of smoky rooms is much more frequent than where chimneys are longer.

If there are two fires in the same room, or in any rooms open to each other, and having chimneys of different lengths,—and if the doors and windows are very close, so that air to supply the draughts cannot enter by them, the taller chimney will overpower the shorter, and cause it to smoke into the room; just as the long leg of a syphon overcomes the short one, or as a long log of wood, held down in water by a cord passing from it round a pulley at the bottom to a shorter leg [illegible] rise, and pull down the shorter leg.

A long chimney, for the reasons [illegible] rent of air to pass through the fire very rapidly [illegible] formly than can be effected by any bellows or blowing [illegible]. On these accounts, for fires of steam-engines [illegible] it is the means of blowing generally preferred. [illegible] tense heat that art can produce in a furnace [illegible] air-furnace, that is to say, [illegible] ney. The importance of length in a chimney [illegible] gular appearance of [illegible] towns, where steam-engines abound.

When we heap dying embers together [illegible] sing among them may become [illegible] ble altitude, this column has the effect of blowing them [illegible] and helps to light them up again. [illegible] thrown upon the top of a half-extinguished fire [illegible] blaze afresh, by causing a more rapid current [illegible] through it from below.

The action or draught of a chimney depends [illegible] in which the air in it is heated, [illegible] dilatation or lightness, [illegible]

In what are called *open fire-places*, [illegible] ting-rooms of Britain, a large quantity [illegible] from the apartment enters the chimney above the fire and mixes with the hot air from the fire [illegible] cends more slowly than [illegible] proportion to the degree of mixture. The effect of [illegible] a part of this cold air, [illegible] applied across the opening of the chimney [illegible] entrance:—almost instantly a [illegible] the fire begins to roar as [illegible] often used to blow the fire [illegible] smoky chimney, by increasing the draught. [illegible] *register stove* is a kindred contrivance. [illegible] is a flap placed in the throat of the chimney [illegible] widen or contract it at pleasure. Because this flap is generally opened enough only to allow the air to pass which rises directly from the fire, the chimney receives only very hot air, and therefore acts well. The register stove often cures smoky chimneys: and by preventing the too ready escape of the moderately warmed air of the room, of which so much is wasted by a common fire-place, it also saves fuel. In what are called *close fire-places*, as those of steam-engines, or brewers' coppers, when the furnace door is shut, no air can enter the chimney but directly through the fire: hence the action of such chimneys is very powerful.

In a room with two fires, or in drawing-rooms communicating with each other, although the chimneys be of equal length, that one over the best fire will act the most strongly; and if the doors and windows be so close, as to prevent a sufficiency of air from entering by them to supply both fires, cold air will enter by that chimney which has the weakest fire, and the smoke from it will spread into the room. How often is an assembling dinner party annoyed by the smoke of a second drawing-room fire which had just been lighted before their arrival, and which had therefore to contend with the antagonist fire, already in powerful action all the day. In such a case, while only one fire is lighted, the cold chimney admits the air to feed it, just as an open pane in the window would do. A room may be so close that no air can find entrance, and in such a case the smoke of a fire there must flow into the room.

When all the windows and doors of a house fit so closely as not to admit air for the acting chimneys, the supply comes down the chimneys that are not in use. From inattention to this fact, many a good chimney has the reputation of being smoky, because on the attempt being made to light a fire in it, the smoke at first is always thrown back. The truth is, that when the servant begins to light the fire, there is a downward current in the chimney, which repels, of course, any heated air and smoke that approaches it, and spreads them over the whole house; but were the servant to shut the room-door for a few minutes, so as to cut of communication with the other *drawing* chimneys in the house, and at the same time were to open the window, the chimney would act at once; and when sufficiently heated, would continue to act in spite of the others, and as well as they.

There are some cases of smoky rooms which are not so easily corrected as what we have now mentioned. When a low house stands near a lofty one, the wind, because obstructed by the latter, becomes a gathering or condensatiŏn of air against the wall; and if the top of a low chimney be there, the compressed air enters it, and pours downwards. The same happens occasionally from the proximity of trees or rocks. In such cases, to avoid the influence, chimneys are often made very lofty. Again, whenever from the nature of buildings, eddies of wind occur, as at street corners, &c., chimneys do not act regularly. It is proverbial, that corner-houses, or those at the ends of a row, are smoky houses, and the uniformity of architecture in a street is often destroyed by the necessity of lengthening their chimneys. Smoke is often found descending into a room where there is no fire, *viz.* when the empty chimney is serving as an inlet for air to the house, and the smoke of a neighbouring chimney is passing closely over the top of it.

In summer, when fires are not in use, there is often a strong smell of soot perceived in the apartments during the whole of the day, but which ceases at night. The reason is, that during the day the chimney is colder than the external air: and by condensing the air which enters, it causes a downward current through the soot. During the night, again, when the external air becomes colder owing to the absence of the sun, the chimney, by retaining the heat absorbed during the day, is hot enough to warm what enters, and to cause an upward current. These currents in chimneys left open during the days and nights of summer, are almost as regular as the land and sea breezes of tropical countries.

All these remarks prove how important it is to be able to conceive clearly of the motions going on, according to the simple laws of matter, in the invisible air around us. Were such subjects better and more generally understood, many prevalent errors in the arts of life would soon be corrected, and we should have a corresponding improvement in the comforts and health of the community. We are filled with admiration on discovering how perfectly the simple fact of a lighter fluid rising in a heavier, provides a constantly renewed supply of fresh air to our fires, which supply we should else have to furnish by the unremitted action of some expensive blowing apparatus; but the operation of the law is still more admirable as respects the supply of the same vital fluid to breathing creatures. The air which a man has once respired becomes poison to him; but because the temperature of his body is higher than that of the atmosphere around him, as soon as he has discharged any air from the lungs, it ascends away from him into the great purifying laboratory of the atmosphere, and new air takes its place. No art or labour of his could have done half so well what this simple law unceasingly and invisibly accomplishes, without effort or attention on his part, and in his sleeping as in his waking hours.

The warming and ventilating of houses

is an important art, founded chiefly on the foregoing considerations, and at present too little understood, not only by the public at large, but even by medical practitioners, whose management of disease, though judicious in other respects, is often rendered vain by error or omission in this.

Excellent fuel is so cheap in Britain, owing to the profusion with which beds of rich coal are scattered among the mineral treasures of this favoured portion of the earth, that a careless expenditure has arisen; which however, instead of securing the comfort and health that might be expected, has led to plans of warming which often prove destructive of both. The mischief lies chiefly in the unsteadiness or fluctuations of our domestic temperature. In cold countries again, where fuel is more scarce, as in the north of continental Europe, the necessity for economy has led to contrivances which give steady temperature and impunity.

In cold countries to retain and preserve the heat once obtained, the inhabitants use thick walls, double windows, close joinings, and close stoves or fire places, that is to say, which draw their supply of air not from the apartments where they are placed, that the temperate air of these may not be wasted, but directly from without. Thus fuel is saved to a great extent, and a uniformity of temperature is produced, both as regards the different parts of the room, so that the occupiers may sit with comfort any where; and also as regards tho different times of the day, for the stove being once heated in the morning, often suffices to maintain a steady warmth until night. The temperature can be carried to any required degree, and sufficient ventilation is easily effected. These means prove very favourable to health, by giving a uniform and temperate warmth, instead of extremes and fluctuations.

In England, again, the apartments with their open chimneys, may be compared to great air-funnels, constantly pouring out their warm contents through a large opening, and constantly requiring to be replenished. They thus waste fuel exceedingly, because the chimney being large enough to allow a whole room-full of air to pass away in two or three minutes, the air of the room has to be warmed, not once in the course of the day, but very many times. The temperature in them is made to fluctuate by the slightest causes, as the opening a door, the omitting to stir the fire, &c. The heat is very unequal in different parts of the room, rendering it necessary in general for the company to sit near the fire; where they must often submit to be almost scorched on one side, while they are chilled on the other. There is generally a warm stratum of air above the level of the chimney-piece, surrounding, therefore, the upper part of the bodies of persons in the room, while a cold stratum below envelopes the sensitive feet and legs. As a very rapid current is constantly ascending in the chimney, a corresponding supply must be entering somewhere; and it can only enter by the crevices, and defects in the doors, windows, floors, &c.;—now there is nothing more dangerous to health than to sit near such inlets, as is proved by the rheumatisms, stiff necks, and catarrhs, not to mention more serious diseases, which so frequently follow the exposure. Their is an old Spanish proverb, thus translated,

> "If cold wind reach you through a hole,
> "Go make your will, and mind your soul."

And it is scarcely an exaggeration.

Consumption is the disease which carries off a fifth or more of the persons born in Britain; owing in part, no doubt, to the changeableness of the external climate, but much more to the faulty modes of warming and ventilating the houses. To judge of the influence of temperature in producing this disease, we may consider—that miners who live under ground, and are always, therefore, in the same temperature, are strangers to it, while their brothers and relatives, exposed to the vicissitudes above ground, fall victims—that butchers and others who live almost constantly in the open air, so as to be hardened by the exposure, enjoy nearly equal immunity—that consumption is scarcely known in Russia, where *close* stoves and houses preserve a uniform temperature within doors, while fit clothing gives safety on going out—and that in all countries and situations, whether tropical, temperate or polar, the frequency of the disease bears relation to the manner of change. We may here remark also, that it is not consumption alone which springs from changes of temperature, but a great proportion of acute diseases, and particularly of our common winter diseases. There are few cases in which the invalid has not to remark, that if he had avoided cold on some certain occasion, he might yet have been well.

While temperature is thus so frequently an original cause of disease, it is also a circumstance of the very highest importance in the treatment, as is proved by every fact bearing upon the question. We may, therefore, at first wonder that it should be so negligently and unskilfully controlled as we often see it; disease and death being thence allowed to lurk almost undisturbed in the sanctuaries of our homes: but when we reflect on the subtile and invisible nature of air and heat, and that the science which detects their agencies has been hitherto so little an object of general study, and is indeed of modern discovery, the fact is accounted for.

In England, the open fire-place is so generally in use for common dwellings, and the cheerful blaze is accounted so essential to the happiness of our winter days and long evenings, that it would be difficult to persuade persons to the abandonment of it; let us hope then, that when the subjects which we are now discussing come to be better and more generally understood, the open fire, with close flooring, better or double windows, doors that fit well, register stoves, and good general management may be rendered almost as efficient for warming, and as safe to health, as any other contrivance.

The following considerations present themselves in this place. —Small rooms in winter are more dangerous to health than large ones, because the cold air, entering towards the fire by the doors or windows, reaches the persons in the room before it can be tempered by mixing with the warmer air already around them.—Stoves in the halls and staircases are useful, because they warm the air before it enters the rooms; and they prevent the hurtful chills often felt on passing through a cold staircase from one warm room to another.—It is important to admit no more cold air into the house than is just required for the fires, and for ventilation; hence there is a great error in the common practice of leaving all the chimneys that are not in use quite open:—each admits air as much as a hole in the wall, or an open pane in a window would do.—Perhaps the best mode of admitting air to feed the fires is through tubes, leading directly from the outer air to the fire-place, and provided with what are called throttle-valves, for the regulation of the quantity: the fresh air admitted by them may be made to spread in the room either at once, or after having been warmed during its passage inwards, by coming near the fire.—In a very close apartment, ventilation must be expressly provided for by an opening near the ceiling, to allow the impure air rising from the respiration of the company to pass away. With an open fire, the purpose is effected, by the frequent change of the whole air of the room which that construction occasions.

With a view to have, in rooms intended for invalids, the most perfect security against cold blasts and fluctuation of temperature, and still to retain the so much valued appearance of the open fire, a glazed frame or window may be placed at the entrance to the chimney, so as completely to prevent the passage of air from the room to the fire. The room will then be warmed by the fire through the glass, as a green-house is warmed by the rays of the sun. It is true, that the heat of combustion does not pass through glass so readily as the heat of the sun; but the difference is not important. The glass of such a window must, of course, be divided into small panes; and supported by a metallic frame-work to resist the heat. There must be a flap or door in the frame-work, for the purpose of admitting the fuel and stirring the fire. Air must be supplied to the fire as described above, by a tube leading directly from the external atmosphere. The ventilation of the room may be effected by an opening into the chimney near the ceiling; and the temperature may be regulated with great precision by a valve placed in this opening, and made to obey the dilatation and contraction of a piece of wire affixed to it, the length of which will always depend on the temperature of the room.—The author first contrived the fitting up of a room here described, for the winter residence of a person threatened with consumption; and the happy issue of that particular case, and of others treated on similar principles, has led him to doubt, whether many of the patients with incipient consumption, who are usually sent to warmer climates, and who die there after suffering hardships on the journey, and distress from the banishment sufficient to shake even strong health,—might not be saved, by judicious treatment in properly warmed and ventilated apartments, under their own roofs, and in the midst of affectionate kindred.—And if a boy be almost certainly secured from consumption by being made a miner or a butcher, may we not hope that, when all the influencing circumstances come to be better understood, something of the same immunity may be obtained for persons in all the professions and conditions of civilized society?

It must not be supposed that the remarks made in this section go near to exhaust the very important subject of temperature as affecting health. The questions of *clothing* of *hot and cold bathing*, of *exercise*, and others, equally belong to it, but the consideration of them falls under other departments of study.

Winds or currents in the atmosphere

are also phenomena, in a great measure dependent on the law, that lighter fluids rise in heavier. As oil let loose under water is pressed up to the surface and swims, so air near the surface of the earth, when heated by the sun, rises to the top of the atmosphere, and spreads there, forced up by the heavier air around which rushes inwards, and constitutes wind. The cross currents in the atmosphere, thus arising, are often rendered evident by the motion of clouds or balloons.

If our globe were at rest, and the sun were always acting over the same part, the earth and air directly under him would become exceedingly heated, and there, the air would be constantly rising like oil in water, or like the smoke from a great fire; while currents or winds would be pouring towards the central spot, from all directions below. But the earth is constantly turning around under the sun, so that the whole middle region or equatorial belt may be called the sun's place; and therefore, according to the principle just laid down, there should be over it a constant rising of air, and constant currents from the two sides of it, or the north and south, to supply the ascent. Now this phenomenon is really going on, and has been going on ever since the beginning of the world, producing the steady winds of the northern and southern hemispheres, called *trade winds*, on which in most places within thirty degrees of the equator, mariners reckon almost as confidently as on the the rising and setting of the sun himself.

The trade winds, however do not appear on the earth to be directly north and south, as they are in fact, for the eastward whirling or diurnal rotation of the earth, causes a wind from the north to appear as if coming from the north-east, and a wind from the south as if coming from the south-east. This is illustrated by the case of a man on a galloping horse, to whom a calm appears to be a strong wind in his face: or if he be riding eastward while the wind is directly north or south, such wind will appear to him to come from the north-east, or south-east: —or again, by the case of a small globe made to turn upon a perpendicular axis, while a ball or some water is allowed to run from the top of it downwards:—the ball or water will not immediately acquire the whirling motion of the globe, but will fall almost directly downwards: so that the track if marked upon the globe will appear not as a direct line from the axis to the equator, that is from north to south, but as a line falling obliquely.—It is thus the whirling of the earth which is the cause of the oblique and westward direction of the trade-winds, and not as has often been said, the sun drawing them after him.

The reason why the trade-winds at their external confines, which are about 30° from the sun's place, appear almost directly *east*, and become more nearly *north* and *south* as they approach the central line, is, that at the confine they are like fluid coming from the axis of a turning wheel, which has approached the circumference, but has not yet acquired the velocity of the circumference; while nearer the line, they are like the fluid after it has for a considerable time been turning on the circumference, and has acquired its rotatory motion, appearing at rest as regards that motion, but still leaving sensible any motion in a cross direction.

While, in the lower regions of the atmosphere, air is constantly flowing towards the equator and forming the steady trade-winds between the tropics, in the upper regions there must of course be a counter-current distributing the heated air again over the globe. Accordingly, since reasoning led men to expect this, many striking proofs have been noted. At the summit of the Peak of Teneriffe, observations now prove that there is always a strong wind blowing in a direction contrary to that of the trade-wind on the face of the ocean below. Again, the trade-winds among the West-India Islands are constant, yet volcanic dust thrown aloft from the Island of St. Vincent, in the year 1812, was found, to the astonishment of the inhabitants of Barbadoes, hovering over them in thick clouds, and falling, after coming more than a 100 miles directly against the strong trade-wind, which ships must take a circuitous course to avoid. In sailing from the Cape of Good Hope to St. Helena the sun is often hidden for days together by a stratum of dense clouds passing southward high in the atmosphere; which clouds consist of the moisture raised near the equator with the heated air, and becoming condensed again as it approaches the colder regions of the south.

Beyond the tropics, where the heating influence of the sun is less, the winds occasionally obey other causes than those we have now been considering, which causes have not yet been fully investigated. The winds of temperate climates are in consequence much less regular, and are called *variable;* but still as a general rule, whenever air is moving towards the equator, from the north or south poles where it was at rest, it must have the appearance of an east wind, or a wind moving in the contrary direction to the earth itself, until it has gradually acquired the whirling motion of that part of the surface of the earth on which it is found; and again, when air is moving from the equator, where it had at last acquired nearly the same motion as that part of the earth, on reaching parts nearer the poles, and which have less eastward motion, it continues to run faster than they, and becomes a westerly wind. In many situations beyond the tropics the westerly winds, which are merely the upper equatorial currents of air falling down, are almost as regular as the easterly winds within the tropics, and might also be called trade-winds:—witness the usual shortness of the voyages from New York to Liverpool, and the length of those made in the contrary direction. North of the equator, then, on earth, true north winds appear north-east, and true south winds appear south-west:—which are the two winds that blow in England for three hundred days of every year. In southern climates the converse is true.

While the sun is beaming directly over a tropical island he warms very much the surface of the soil, and therefore also the air over it; but the rays which fall upon the ocean around penetrate deep into the mass, and the superficial increase of temperature is less. As a consequence of this, there is a rapid ascent of hot air over the island during the day, and a cooler wind blowing towards its centre from all directions. This wind constitutes the refreshing *sea-breeze* of tropical islands and coasts. A person must have been among these, to conceive the delight which the sea-breeze brings after the sultry stagnation which precedes it. The welcome ripple shorewards is first perceived on the surface of the lately smooth or glassy water; and soon the whole face of the sea is white with little curling waves, among which the graceful canoe shoots along.

During the night an opposite phenomenon takes place. The surface of the earth, then no longer receiving the sun's rays, is soon cooled, while the sea which absorbed heat during the day, not on the surface only, but through its mass, continues to give out heat all night. The consequence is, that the air over the earth being colder than that over the sea, sinks down, and spreads out on all sides, producing the *land-breeze* of tropical climates. This wind is often charged with unhealthy exhalations from the marshes and forests, while the sea-breeze is all purity and freshness. Many islands and coasts would be absolutely uninhabitable but for the sea-breeze.

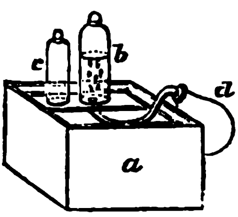
The peculiar distribution of land in the Asiatic part of the globe, produces the curious effect there of a sea-breeze of six months, and a land-breeze of six months. The great continent of Asia lies chiefly north of the line, and during its summer the air over it is so much heated, that there is a constant steady influx from the south—appearing south-west, for the reason given in a preceding page; and during its winter months, while the sun is over the southern ocean, there is a constant land-breeze from the north—appearing, for a like reason, north-east. These winds are called *monsoons;* and if their utility to commerce were to be a reason for a name, they also deserve the name of trade-winds. In early periods of navigation, they served to the mariner the purpose of compass, as well as of moving power; and one voyage outward, and another homeward, with the changing monsoons, filled up his year.—On the western shores of Africa and America also, the trade-winds are interfered with by the heating of the land; but much less than in Asia, and always in accordance with the laws now explained.

The frightful tornadoes, or whirlwinds, which occasionally devastate certain tropical regions, making victims of every ship or bark caught on the waters, and the violent gusts or squalls met with every where, are owing to some sudden chemical changes in the atmosphere, not yet fully understood.

The Pneumatic Trough and Gasometer

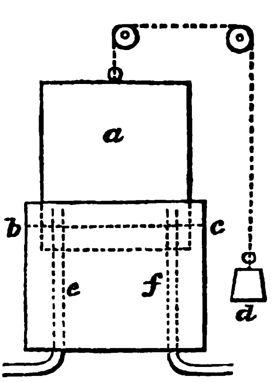
of the chemist are contrivances constantly displaying the truth now under consideration, "that a lighter fluid is pushed up or floats in a heavier." They are important parts of the apparatus for operating on substances while in the form of air.

The trough *a* may be made of tin plate or wood, and of any convenient size. It is nearly filled with water, and has at one end, under the surface of the water, a shelf, on which jars or vessels, as *b* and *c*, may rest. Any particular air or gas is preserved separate from the atmosphere, by being placed in one of these jars with the mouth downwards. The gas is passed into the jar by first immersing this in the trough, so as to fill it with water and to expel the common air from it; and by then holding its mouth over the gas while rising under the water from another vessel or pipe;—*d* represents a long-necked vessel, used to contain the ingredients for the production of gases by chemical action. The gas, of course rises to the top of the jar *b*, and gradually displaces the water. During the operation of filling, the jar may be supported by the hand or by resting upon the shelf;—in the latter case the air is allowed to rise into it through a hole in the shelf provided with a small funnel gaping downwards to catch the air more readily. The shelf may have room on it for many jars, and it may have more holes than one;



and if the gas under operation be such that water absorbs or changes it, some other liquid, as mercury, may be used instead of water.

A *gasometer* or *gas-holder*, is merely a larger jar or vessel *a*, dipping into water, with its mouth downwards, in a trough of its own shape, *b c*, and so supported or counterpoised by a weight by *d*, over pulleys, that very little force may suffice to move it up or down. Air forced into it through a pipe *f* opening under it, causes it to rise or float higher in proportion to the quantity. The air is made to pass from it again when wanted, through the same tube or through another as *e*.



The huge gasometers, exceeding in size an ordinary house, and containing the supply of gas for the lamps of a town, are vessels suspended as above represented, in great pits or troughs of cast-iron, filled with water. The gas issues with force proportioned to the downward pressure of the containing vessels, which may be nicely regulated in a variety of ways, and is generally made to equal the action of a column of water of two inches in height, that is to say, such that a pipe in communication with the vessel at one end, and dipping into water with the other shall allow gas to escape, if immersed less than two inches perpendicularly.

It would be encroaching on the province of the chemist to treat here particularly of the substances which most generally exist in the aeriform state; but to give an increased interest to the description of the gas-apparatus, a few leading facts may be mentioned.

Of about fifty distinct substances known as the materials of our globe, five, when uncombined, and under common circumstances, of heat and pressure, exists as airs or gases. The water used to fill the apparatus above described is a compound of two of these substances, *viz. oxygen* and *hydrogen*. By directing an electrical current through water, it is gradually decomposed, and from one end of a tube in it, a stream of aeriform oxygen may be received, and from the other end a stream of hydrogen. The two gases may be again united to form water, by mixing them in a proper vessel, and passing an electric spark through them. They combine with explosion.

This *oxygen*, so called from its relation to acids, has been accounted, for many reasons, the most important substance in nature. It forms eight-ninths, by weight, of the ocean; one-fourth of the atmosphere; and, perhaps, one-fourth of the solid matter of the globe: possibly, therefore, although most persons think of it only as an air or gas, there is not a millionth part of the quantity of oxygen in the world, existing as air. It unites readily with most other substances, and generally with such intense action as to produce the phenomenon of fire or cumbustion;—the word *combustible* chiefly applies to substances that quickly combine with oxygen.

Oxygen assumes a singular variety of character in its different combinations. Thus with *hydrogen*, it forms water; with *lead*, it forms the substance called *red-lead;* with *nitrogen*, in one proportion, it forms *atmospheric air*, in another proportion, the *nitrous oxide*, or what is called the *laughing gas*, in a third, the acid called *aquafortis;* with sulphur, it forms the *sulphuric acid* or *oil of vitriol;* with iron, and all metals, it forms their ores called oxides; and so forth. But the most important character in which we know it, is as that ingredient of our atmosphere, without which animals and vegetables cannot live, and fire cannot burn. Oxygen, from this part of its history, was long named *vital* or *pure air*.

Pure oxygen in the state of air is a little heavier than common air; but when holding a quantity of charcoal in solution, it forms aeriform *carbonic acid*, which is nearly twice as heavy as common air, and may be poured out of one vessel into another like water. Carbonic acid is what issues from soda-water, brisk ale, champaign, &c., while they sparkle. If drawn into the lungs in breathing, it is fatal to life. A charcoal fire left in a close room with sleeping persons, has often been fatal to them, because carbonic acid gas is the product of the combustion. The famous *Grotto del Cane*, in Italy, is a cavern always full of carbonic acid which springs into it from below, as water springs into a well, and runs over like water from a well. The grotto received its name from the circumstance of dogs dying instantly when thrown into it. Carbonic acid rising in fermentation has often proved fatal to persons leaning over the edge of fermenting vats. It is common to see a rat die instantly, in the attempt to run along a plank lying across the mouth of a fermenting tub.

Hydrogen, the other ingredient of water, and so called from its relation to *water*, when in the state of air, is nearly fifteen times lighter than oxygen. With it balloons are filled. When it holds in solution a certain quantity of carbon or charcoal, it becomes the common gas used for illumination, and is the fire-damp of mines, of which the burning and explosion are so terrible. It forms one-ninth of the ocean, and much of animal and vegetable bodies; and probably a little of it floats separately in the higher regions of the atmosphere.

Nitrogen, so called from its relation to *nitric acid*, is the third and last substance which we shall mention. It is what remains of the atmosphere when the oxygen is removed. It forms about three-fourths of the atmosphere, one-fourth of animal flesh, and is found in small quantities in other combinations. It will not support life by itself, and therefore formerly was called *azote:* with a larger proportion of oxygen it forms *nitric acid*, or the *aquafortis* of old.

The last few paragraphs may serve to show how many of the manipulations of chemistry are directed by the principles of physics or mechanical philosophy, and therefore how essential to the chemist the preliminary study of physics becomes.

PART III.

THE DOCTRINE OF FLUIDS.

SECTION III.—HYDRAULICS—PHENOMENA OF FLUIDS IN MOTION.

ANALYSIS OF THE SECTION.

Whether the particles of matter exist in the form of solid or fluid, the circumstance does not affect their properties of INERTIA *and* GRAVITY. *Hence liquids and airs, in proportion to their quantity, resist, receive, and impart motion, and have weight and friction, as is true of solids. This is seen in the phenomena of*

1. *Fluids moving in pipes and channels, or issuing from them.*
2. *Waves.*
3. *Fluids resisting the motion of bodies immersed in them; or themselves moving against other bodies.*
4. *Fluids lifted or moved in opposition to gravity.*

" *Fluids moving in channels or issuing from them.*"

WATER in a tube connected with a reservoir, will rise to the level of the liquid surface in the reservoir. If such a tube be then cut off, except a small part at the bottom, prepared as a jet pipe, the water will spout from this still to the same height. Now, as a body shot upwards has the same velocity in departing, which it again acquires by falling to the same place (with a little correction for the resistance of the air, as explained at page 104,) it follows, that fluid issues from any orifice with as much velocity as a body would acquire in falling from the level of the fluid surface in the reservoir to the orifice. By referring then to the law of falling bodies, as explained at page 102, we may learn the velocity of the issue of water in any case, and therefore the quantity delivered by an opening of a given magnitude. As a body by gravity falls sixteen feet in the first second, with speed gradually increasing, and at the end of the second has a velocity of thirty-two feet per second: therefore a reservoir with an opening of an inch square at sixteen feet below the water's surface, will deliver in one second of time, with a certain deduction for friction, thirty-two feet of a jet of water of a inch square; and according to the same rule, an opening at four times the depth, should deliver a double quantity; at nine times the depth, a triple quantity; and so on; as really happens. An inquirer is at first surprised that the quantity should not be quadruple, where the height of column or pressure forcing it out is quadruple: but on reflection, he may perceive that the water by running away more quickly from a pressure, is less affected by it; and when only twice as much water is forced out, there is still four times as much work done, because each particle issues with twice the force or velocity. Because a body shot upward with a double velocity gains a quadruple height (see page 105,) the jet issuing with only double velocity from four times the depth, still reaches the level of the surface of the reservoir.

The knowledge of this rule for discharging orifices is of the greatest importance in the construction of water-works, because when joined with another rule assigning the effect of friction in pipes, it ascertains the quantity of water which a conduit of any certain magnitude, and elevation will deliver.

It is a curious fact, that more water issues from a vessel through a short pipe, then through a simple aperture of the same diameter with the pipe; and still more issues if the pipe be funnel-shaped, or wider towards its inner extremity. The reason is, that the issuing particles coming from all sides to escape, cross and impede each other in rushing through a simple opening, as is proved by the narrow neck which the jet exhibits a little beyond the opening; but in a tube; this narrowing of the jet cannot happen without leaving a vacuum around the part, and the pressure of the atmosphere, resisting the vacuum, causes a quicker flow. The funnel-shape again leads the water by a more gradual inclination to the point of exit, and thus considerably prevents the crossing among the particles; while its mouth surrounds the narrow neck of the jet.

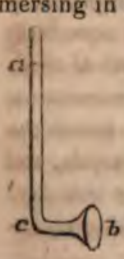
The friction or resistance which fluids suffer in passing along pipes is much greater than might be expected. It depends chiefly upon the particles near the outside being constantly driven from their true course by the irregularities in the surface of the pipe. An inch tube of two hundred feet in length, placed horizontally, is found to discharge only a fourth part of the water which escapes by a simple aperture: and air passing along tubes, is so much retarded (as was discovered to his cost, by a person who erected a great bellows at a water-fall, to blow a furnace two miles off,) that when gas-lights were first proposed, some engineers feared that the circumstance would be fatal to the enterprise.

Higher temperature in a liquid increases remarkably the quantity discharged by an orifice or pipe, by diminishing that cohesion of the particles which exists in certain degrees in all liquids, and effects so much their internal movements.

The flux of water through orifices under uniform circumstances is so steady, that before the invention of clocks and watches, it was employed as a means of dividing time. The vessels were called *clepsydræ*. The common hour-glass of running sand is another modification of the same principle.

The progress of water in an open conduit, such as the channel of a river or aqueduct, is influenced by friction in the same manner. But for this, and the effect of bending, a river like the Rhone, drawing its waters from an elevation of 1,000 feet above the level of the ocean, would pour them out, with the velocity of water issuing from the bottom of a reservoir 1,000 feet deep; that is to say, at the rate of about 170 miles per hour. The ordinary flow of rivers is about three miles per hour, and their channels slope three or four inches per mile.

The velocity of a water current is easily ascertained by immersing in it the end *b* of such a tube as here represented, with its funnel-shaped mouth turned towards the stream. The water in the tube will stand above the surface of the stream, marking a velocity of current the same as of an issue from a reservoir, in which water stood at a like elevation above the orifice, as explained in page 372. A similar contrivance may be made to measure the velocity of the wind,



by having the shoulder of the tube at *c* bent further down and filled with water.—A common mode of telling the velocity of an open stream, is to observe with a stop-watch the progress of a body floating in it; and knowing the velocity of the water, and the depth and width of the channel, the quantity delivered in a given time becomes a matter of simple calculation. The speed of the wind may be ascertained by measuring that of the shadow of a cloud passing across a field of known dimensions.

The friction of water moving in water is such that a small stream directed through a pool, and rapid enough to rise over the opposite bank, will soon empty the pool. Extensive fens have been drained on this principle. The friction between air and water is also singularly strong, as is proved on a great scale by the magnitude of the ocean-waves, which are consequences of it; and on a small scale by the amusing experiment of making a light round body dance or play upon the summit of a water-jet,—a chief cause of its remaining there being, that the current of air rising around the jet by reason of the friction, presses it inwards again, whenever it inclines to fall over. A little oil thrown upon the surface of water soon spreads as a thin film all over it, and defends it from the farther contact and friction of air. If this can be done at the windward side of a pond where the waves begin, the whole surface soon becomes as smooth as glass; and even out at sea, where the commencement of the waves cannot be reached, oil thrown upon them smooths their surface, and prevents their curling over or breaking. It is said that boats having to reach the shore through a raging surf have been preserved by the crews first spilling a cask of oil in the offing.

The most magnificent examples that ever existed, or probably ever will exist, of artificial water-courses, were the aqueducts of ancient Rome, about twenty in number. Several of them exceeded forty miles in length, passing through mountains, in their way, and borne on tiers of splendid arches across the valleys. They were constructed of such durable materials, and so skilfully, that the principal of them are perfect to this day. Considered as one object, they rank, in point of magnitude, before any other work of human labour, not excepting the pyramids of Egypt.

While the aqueducts are cited as specimens of grandeur, we may mention the fountains in the gardens of Italy and France as specimens of beauty. Those at Versailles are well known. In them the most magical effects are produced by varying the ways in which water is made to spout from orifices. In one place it is seen darting into the air as a straight upright pillar: in others many such pillars rise together, like giant stalks of corn: sometimes, an inclinations given to the jets, makes them bend so as to form beautiful arches, of which some appear as the roofs of apartments built of water; while others mingle together with endless variety: here and there water-throwing wheels send out spiral streams, and hollow spheres with a thousand openings, are the centres of immense bushes or trees of silvery boughs. Such effects, amidst cascades, smooth lakes, and scenes of lovely landscape, constitute a whole as enchanting, perhaps, as art by moulding nature has ever produced, or even as fancy has conceived.

" Waves."

The form, magnitude, and velocity of waves are subjects admitting of deep mathematical research; and are rendered the more interesting, because certain phenomena of *sound* and *light* are of kindred nature. Here, however, they must be treated with all possible brevity.

A stone thrown into a smooth pond, causes a succession of circular waves to spread from the spot where it falls as a common centre. They become of less elevation as they expand, and each new one is less raised than the preceding, so that gradually the liquid mirror is again as perfect as before. Several stones falling at the same time in different places, cause crossing circles, which, however, do not disturb the progress of each other,—a phenomenon seen in beautiful miniature at each leap of the little insects which cover the surface of our ponds in the calm hours of summer.—The rationale of the formation of waves in such cases is as follows. When the stone falls into the water, because the liquid is incompressible, a part of it is displaced laterally, and becomes an elevation or circular wave around the stone. This wave then falls downwards and outwards in obedience to the laws of fluidity, and the circle is seen to spread. In the mean time, where the stone descended, a hollow is left for a moment in the water, but owing to the surrounding pressures, is soon filled up, by a sudden rush from below. The rising water does not stop however at the exact level of that around, but like a pendulum sweeping past the centre of its arc, it rises as far above the level as the depression was deep. This central elevation now acts as the stone did originally, and causes a second wave, which pursues the first; and when the centre subsides, like the pendulum still, it sinks again as much below the level as it had mounted above: hence it has to rise again, again to fall, and this for many times, sending forth a new wave at each alternation. Owing to the friction among the particles of the water, each new wave is less raised than the preceding, and at last the appearance dies away.

A wave passing through any gap or opening, spreads from it as a new centre; and a wave coming against a perpendicular surface of wall or rock, is completely reflected from it, and acquires the appearance of coming from a point as far beyond the wall, as its real origin or centre is distant on the side where it is moving.

So absolutely level is a liquid surface, and so sensitive, that the effect of any disturbing cause is perceived at great distances. A boat rowed across a still lake, ruffles its surface to a great extent; and although the widening waves become at last so faint as not to be perceptible to the eye, they still produce a rippling noise where they fall among the pebbles on the shore. In seas liable to sudden but partial hurricanes, the roar of breakers on distant coasts often tells of the storm which does not otherwise reach them. The author once, in the eastern ocean, had an opportunity of contemplating waves of extraordinary magnitude rolling along during a gloomy calm, and therefore with unbroken surface, appearing like billows of molten lead. It was afterwards ascertained that at that very time, about a hundred miles to the north-east, four of the finest ships of the India Company were perishing in a storm.—In the polar seas, which are comparatively tranquil, because defended from the wind by surrounding islands of ice, a few sudden waves are occasionally observed, and quickly all is calm again. Such a phenomenon announces that the occurrence described at page 278 has happened somewhere, of an island of ice turning over, when the place of its centre of gravity is changed by partial melting.

The common cause of waves is the friction of the wind upon the surface of the water. Little ridges or elevations first appear, which by continuance of the force, gradually increase, until they become the rolling mountains seen where the winds sweep over a great extent of water. The heaving of the bay of Biscay, or still more remarkably, that of the open ocean beyond the southern capes of America and Africa, exhibits one extreme, and the stillness of the tropical seas, which are sheltered by near encircling lands, exhibits the other. In the vast archipelago of the east, where Borneo, and Java, and Sumatra lie, and the Molucca islands and the Phillipines, the sea is often fanned only by the land and sea breezes, and is like a smooth bed, on which these islands seem to sleep in bliss—islands in which the spice and perfume gardens of the world are embowered, and where the bird of paradise has its home, and the golden pheasant, and a hundred others of brilliant plumage, among thickets so luxuriant, and scenery so picturesque, that European strangers find there the fairy land of their youthful dreams.—One who has seen these islands in the morning of his days, may be pardoned for alluding to the pleasure they gave.

In rounding the Cape of Good Hope, waves are met with, or rather a swell, so vast, that a few ridges and a few depressions occupy the extent of a mile. But these are not so dangerous to ships as a *shorter* sea, as it is termed, with more perpendicular waves. The slope in the former is so gentle, that the rising and falling are scarcely felt; while the latter, by the sudden tossing of the vessel, is often destructive. When a ship is sailing before the wind, and riding over the *long swell*, she advances as if by leaps: for while each wave passes, she is first descending head-long on its front, acquiring a velocity so wild that she can scarcely be steered; and soon after when the wave has glided under her, she is climbing on its back, and her motion is slackened almost to rest, before the following wave arrives.

The velocity of waves has relation to their magnitude. The large waves just spoken of, proceed at the rate of from thirty to forty miles an hour.—It is a vulgar belief, that the water, itself advances with the speed of the wave, but in fact the *form* only advances, while the *substance*, except a little spray above remains rising and falling in the same place, with the regularity of a pendulum. A wave of water, in this respect, is exactly imitated by the wave running along a stretched rope when one end is shaken; or by the mimic waves of our theatres, which are generally undulations of long pieces of carpet, moved by attendants. But when a wave reaches a shallow bank or beach, the water becomes really progressive, because then, as it cannot sink directly downwards, it falls over and forwards, seeking the level.

So awful is the spectacle of a storm at sea, that it is generally viewed through a medium which biases the judgment; and, lofty as waves really are, imagination pictures them loftier still. Now no wave rises more than ten feet above the ordinary sea-level, which, with the ten feet that its surface afterwards descends below this, give twenty feet for the whole height, from the bottom of any water-valley to an adjoining summit. This proposition is easily verified by a person who tries at what height, on a ship's mast the horizon remains always in sight over the top of the waves—allowance being made for accidental inclinations of the vessel, and for her sinking in the water to much below her water-line, at the time when she reaches the bottom of the hollow between two waves. The spray of the sea, driven along by the violence of the wind, is of course much higher than the summit of the liquid wave; and a wave coming against an obstacle, may dash to a great elevation above it. At the Eddystone light-house, when a surge breaks which has been growing under a storm all the way across the Atlantic, it dashes even over the lantern at the summit.

The magnitude of waves is well judged of when they are seen breaking on an extended shore or beach. In the deep sea the wave is only an elevation of the water, sloping on either side; but as it rolls towards the shore, it becomes in front more and more perpendicular, until at last it curls over and falls with its whole weight, and when several miles of it break at the same instant, its force and noise may shake the country around.

On the east, or Coromandel coast of India, at certain seasons, vast waves are constantly breaking; and as there are no good harbours there, communication between the sea and land is rendered impossible to ordinary boats. The natives of the coast, at Madras, for instance, have hence become almost amphibious. They reach ships beyond the breakers by the help of what are called *catamarans*, consisting of three small logs of wood tied together. On these they secure themselves, and boldly advance up to the coming wall of water, which they shoot into, and rise to the smooth surface beyond it, like water-fowls after diving. Boats unsuited to the breakers often perish in them. The author had gone on shore with a watering party on the coast of Sumatra, and during the hours spent there, a swell had arisen in the sea, which on their return was already bursting along the beach and across the river's mouth in lofty breakers. The boat in which he happened to be, regained the ship in safety, but a larger boat which followed at a short distance was overwhelmed, and an officer and part of the crew perished.

There is a phenomenon observed at the mouths of many great rivers, called the *Boar*, which has resemblance to a wave. When the tide returning from the sea meets the outward current of the river, and both have the force which in certain situations belongs to them, the stronger mass from the ocean assumes the form of an almost perpendicular wall, moving inland with resistless sweep. This is called the boar. It is in fact the great sea-wave of the tide, which is produced twice a day by the attraction of the moon, rolling in upon the land and inlets. In the different branches of the Ganges the boar is seen in a remarkable degree. Smaller boats and skiffs cannot live where it comes; and as it passes the city of Calcutta, even the large ships at anchor there are thrown into great commotion, and sometimes are torn from their moorings.—The nature and effects of this boar are strikingly illustrated upon certain coasts where extensive tracts of sand are left uncovered at low water. In such situations, of which there are many on the western shores of Britain, the returning tide is seen advancing with steep front, and with such rapidity, that the speed of a galloping horse can scarcely save a person who has incautiously approached too near. Many, every year, are the victims of temerity or ignorance on these treacherous plains.

It has been proposed lately to construct *submarine boats*, or vessels calculated to swim so deep in the water as to be below the superficial motion of the waves, and therefore beyond the influence of storms at the surface. Such a boat has been tried with considerable success; and men's increasing familiarity with submarine matters since the invention of the diving-bell, may ultimately lead to improvements rendering the submarine vessel so commodious and safe, that those persons who dislike the sickening motion of the surface, may have it in their option to sail underneath.

"*Fluids resisting the motion of bodies immersed in them, or themselves moving forcibly against other bodies.*" (*See the analysis, page* 371.)

The same force is required to give, or to take away, or to bend motion, in a fluid, as in an equal quantity of solid matter. A pound of water enclosed in a bladder, is not more easily thrown to a given height than a pound of ice, or of lead; nor, if falling into the scale of a weighing-beam, does it require less as a counterpoise; nor if made to revolve at the end of a sling, does it render the cord less tight.

Many persons looking carelessly at this subject, would expect, that if a body moving through a fluid at a given rate meets a given resistance, it should just meet double resistance when moving twice as fast. Now the resistance is four times greater with a double rate.

This fact, when more closely examined, is easily understood.

A boat which moves one mile per hour, displaces a certain quantity of water, and with a certain velocity;—if it move twice as fast, it of course displaces twice as many particles in the same time, and requires to be moved by twice the force on that account; but it also displaces every particle with a double velocity, and requires another doubling of the power on this account: the power than being doubled on two accounts, becomes a power of four. In the same manner with a speed of three, three times as many particles are moved, and each particle with three times the velocity; therefore a force of nine is wanted to overcome the resistance; for a speed of four, a power of sixteen is wanted; for a speed of five, a power of twenty-five; and so forth; the corresponding numbers, up to a speed of ten, being as here shown,

Speed …………………………………	1	2	3	4	5	6	7	8	9	10
Corresponding resistance ……	1	4	9	16	25	36	49	64	81	100

Thus, even if the resistance at the bow of a vessel were all that had to be considered, the force of one hundred horses would only drag the vessel ten times as fast as the force of one horse, the relation being that which mathematicians express by saying *that the resistance increases as the square of the speed.* But there is another important element in the calculation, *viz.* the lessening of the usual water-pressure on the stern of the vessel as she moves forward, on account of which, the force required to produce an increased velocity is still considerably greater than as noted in the table.

There is not a more important truth in physics than that here treated of; it explains so many phenomena of nature, and becomes a guide in so many matters of art. We shall now set forth some interesting examples chosen indifferently from the two classes mentioned.

It explains at what a heavy expense of coal high velocities are obtained in steam-boats. If an engine of 49 or 50 horse power would drive a boat 7 miles an hour, two engines of 50, or one of 100, would be required to drive it 10 miles, and three such to drive it 12 miles;—supposing the resistance at the bow, as already stated, to be the measure of the whole work done, which it is not, and that engines work to the same advantage with a high velocity as with a low, which they do not.—For the same reasons, if all the coal which a ship could conveniently carry were just sufficient to drive her 1,000 miles, at the rate of 12 miles per hour, it would drive her much more than 3,000 at a rate of 7 miles per hour; and much more than 6,000 at a rate of 5 miles per hour. This is a very important consideration, for persons concerned in steam navigation to distant parts.

The same laws shows the folly of putting very large sails on a ship; the trifling advantage in point of speed by no means compensating for the additional expense of making and working the sails, and the risk of accidents in bad weather. The ships of the prudent Chinese have not, for the same tonnage, one-third so much sail as those of Europe, and yet they move but a little slower on that account. A European ship under jury-masts does not lose so much of her usual speed as most people would expect.

This law explains also why a ship glides through the water one or two miles an hour when there is very little wind, although with a strong breeze she would only sail at the rate of eight or ten miles. Less than the 100th part of that force of wind which drives her ten miles an hour will drive her one mile per hour, and less than the 400th part will drive her half a mile. Thus also, during a calm, a few men pulling in a boat can move a large ship at a sensible rate.

These considerations show strikingly of what importance to navigation it might be to have, as a part of a ship's ordinary equipment, one or two water-wheels, to be affixed upon the ship's side when required, like the paddle-wheels of a steam-boat, and by turning which the crew might easily deliver themselves from the tedium, and often disastrous consequences of a long calm at sea.—This idea occurred to the author while in a ship completely becalmed for weeks on the Line; during which most wearisome period, the breezes were often seen roughening the water a mile or two farther on; and any means that could have enabled the ship's company to advance her that little distance, might have saved the delay. The wheels might be driven by connexion with the capstan, which under such circumstances, the crew would most willingly turn to escape from their inactivity. Delay in a large vessel with troops on board often costs hundreds of pounds per day, and may retard the execution of important projects.—But the propelling of the ship in a calm seems by no means the most important purpose which such wheels might serve. If from disease, fatigue, or other cause, the crew were inadequate to existing necessities, two wheels affixed to the extremities of an axis running across the ship might be equivalent in many cases to additional hands, or to a steam-engine of great power; for when acted upon by the water as the ship sailed, they would turn with the force of water-wheels on shore, and might be made to move the pumps, to hoist the sails, and to do any work which a steam-engine could perform. Many a gallant vessel has perished because the exhausted crew could no longer labour at the pumps, and in cases where such water-wheels or a windmill-wheel in the rigging would have performed the duty most perfectly.

The law that resistance to a body moving in a fluid increases in a greater proportion than the speed of the body, applies where the fluid is aeriform, as well as where it is liquid.

A bullet shot through the air with a double velocity, for the reason assigned above, experiences four times as much resistance in front as with a single volocity: the motion is retarded also by the diminution of the usual atmospheric pressure of 15*lbs.* per inch on the posterior surface, which diminution is proportioned to the speed. It is further true, that when the velocities of bodies moving in air are very great, the resistance increases in a still quicker ratio than in liquids,—probably because the compressibility of air allows it to be much condensed or heaped up before the quick moving body. It is useless to discharge a cannon ball with a velocity exceeding 1,200 feet in a second, because the powerful resistance of the air to any velocity beyond that, soon reduces it to that at least.

The rule of mutual action between a solid and fluid, now explained, holds equally when the fluid is in motion against the solid, as when the solid moves through the fluid.

If a ship be anchored in a tide's way where the current is four miles an hour, the strain on her cable is not one fourth part so great as if the current were eight miles.

A wind moving three miles an hour is scarcely felt: if moving six miles it is a pleasant breeze; if twenty or thirty miles, it is a brisk gale; if sixty, it is a storm; and beyond eighty, it is a frightful hurricane, tearing up trees and destroying every thing.

Supposing the wind to move one hundred miles per hour, there are one hundred times as many particles of matter striking any body exposed to it, as when it moves only one mile per hour, and each particle strikes moreover with one hundred times the velocity or force: therefore, the whole increase of force is a hundred times a hundred, or ten thousand. This explains how the soft invisible air may by motion acquire force sufficient to unroof houses, to level oaks which have been stretching their roots around for a century, and in some West-India hurricanes, absolutely to brush every projecting thing from the surface of the earth.

The law of rapidly increasing resistance assigns a limit to many velocities, both natural and artificial.

It limits the velocity of bodies falling through the air. By the law of gravity, a body would fall with a constantly accelerating speed, but as the resistance of the air increases still more quickly than the speed, at a certain point, this resistance and gravity balance each other, and the motion becomes uniform.

The *parachute*, by means of which a person may descend to the earth with safety from a balloon at any elevation, resembles a large flat umbrella. The aeronaut attaches himself underneath it, and when it is let loose from the balloon, he is supported by the resistance which its broad expanse experiences in falling through the air. After the first second or two, for the reason stated above, it descends with a uniform motion; and its breadth is generally made such, as to allow a velocity of about eleven feet in a second, or that which a man acquires in jumping from a chair two feet high.

No ship sails faster than fifteen miles in an hour.

No fish swims with a velocity exceeding twenty miles an hour; not the dolphin, when shooting a-head of our swiftest frigates, nor the salmon, when darting forward with speed which lifts him over a waterfall of many feet.

And the flight of birds through the thin air has a limited celerity. The crow, when flying homewards against the storm, cannot face the wind in the open sky, but skims along the surface of the earth in the deep valleys, and wherever the swiftness of the wind is retarded by terrestrial obstructions. The great albatross can stem upon the wing the current of a gale, keeping company with a driving ship where the air is passing at the rate of a hundred miles an hour, but perhaps this is the limit to which winged speed, and therefore living speed may reach. The bird called the *stormy petrel* abides chiefly in the midst of the Atlantic Ocean, but the irresistible violence of the wind occasionally sweeps it from the waves, and causes its appearance on the western shores of Europe. Vessels from the high sea, approaching a coast from which the wind blows, generally become resting-places to exhausted land birds, that have been driven off the shore by wind which they had not strength of wing to stem;—sad evidences of the myriads which are constantly perishing where no resting-place is found, and where no human eye notes their fate.

The action or resistance between a meeting fluid and solid, is influenced by the shape of the solid.

If a flat surface experience a certain resistance, a projecting surface like that of a sphere or short wedge is resisted in a less degree, and a concave surface in a greater. The explanation is, that a flat or plane surface throws the particles of fluid almost directly outwards from its centre to its circumference—the convex or wedge-like surface again, while displacing them just as far, still does it more slowly, and therefore with less expenditure of force, in proportion as its point is in advance of its shoulder or broadest part—and a concave surface must give to some of the particles a forward as well as a lateral motion. The shape of the hinder part of a solid moving through a fluid is of importance for corresponding reasons.

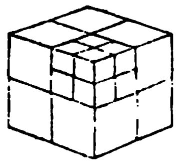
The following are instances of projecting or wedge-like surfaces, intended to diminish the resistance.—Fishes are wedge-like both before and behind.—Birds are so also; and they stretch out their necks while flying, so as to become like sharp points, dividing the air. In the form of the under part of boats and ships, men have imitated the shape of fishes. The light wherries which shoot about upon the surface of the Thames, appear the very essence of all that the imagination can picture of form combining utility and grace. There are boats used in China called *snake-boats*, which are only a foot or two broad, but perhaps a hundred feet in length, and when moved, as they often are, by nearly a hundred rowers, their swiftness is extreme. The problem of which it is the object to assign for a ship's hull or bottom the best possible form that she may have speed of sailing, is not yet completely solved; so that a kind of empiricism prevails in the matter, and very unexpected results often arise. Yet the subject merits much attention, for in war time, when vessels have to chase and to flee, speed becomes of the greatest importance; and at all times the sailor's heart swells with delight, when he finds his well beloved vessel outstripping competitors, both because of the many direct advantages, and of the glory of superiority.

The following instances exhibit the mutual influence of meeting solids and fluids, where the surface of the solid is plane or concave.—In a water-wheel, whether the water be moving against the wheel, as is the case where a stream acts to drive machinery, or the wheel be moving against the still water, as in the case of the paddle-wheels of a steam-boat, the extended faces of the vanes or float-boards give or receive a powerful impulse. When a wheel with float-boards merely dips its lower part into a stream of water, and is driven by the momentum, it is called an *under-shot wheel;* when the water reaches the whee near the middle of its height, and turns it by falling on the float-boards of one side as they sweep downwards in a curved trough fitting them, the modification is called a *breast-wheel;* and when the float-boards are shut in by flat sides, so as to become the bottoms of a circle of cavities or buckets surrounding the wheel, into which the water is allowed to fall at the top of the wheel, and to act by its weight instead of its momentum, the modification is called the *overshot-wheel.* To have a maximum of effect from wheels moved by the momentum of water, they are generally made to turn with a velocity about one-third as great as that of the water: and wheels moved by the simple weight of water usually have their circumference turning with a velocity of about three feet per second. The subject of water-wheels is one of the most important in practical mechanics; for moving water performs a great deal of labour for man.

Oars for boats are made flat, and often a little concave, that the mutual action between them and water may be as great as possible. The webbed feet of water-fowl are oars: in advancing, they collapse like a shutting umbrella, but open outwards in the thrust backwards, so as to offer a broad concave surface to the water. The expanded wings of birds are in like manner a little concave towards the air which they strike. The sails of ships, when they are receiving a fair wind are left slack so as to swell and become hollow.

The resistance between a solid and fluid is nearly proportioned to the breadth of the solid, that is, to the extent of surface opposed by it to the fluid; hence large bodies, because containing more matter in proportion to their surface, are less resisted in proportion to their weight than small bodies of similar form.

A bullet or other solid of two inches diameter, has eight times as much matter in it as a similar solid of one inch diameter, while it has only four times the breath or surface. Thus eight



dice or little cubes put together as here shown, form a larger cube, of which, compared with a single die, the edge is *twice* as long, the surface is *four* times as great, and the quantity of matter is *eight* times as great:—*twenty-seven* dice together form a cube with sides *three* times as long, and the surface *nine* times as great;—and sixty-four dice form a cube with sides *four* times as long, and surface *sixteen* times as great. All solids similar to each other, have this kind of relation, which, in the language of the science of quantity, is called the relation of cubes: they are said to be to each other as the cubes of any of their corresponding line. Hence, if a bullet of eight pounds and a bullet of one pound be shot off with equal velocity, that of eight pounds, because having only four times the surface of the one-pound bullet, but eight times its weight, and therefore eight times its total inertia or force, will go much farther than the other.

This important rule explains why shells and large shot may be thrown four or five miles, while smaller cannon-balls, musket bullets, pistol and swan-shot, and the common small-shot of the sportsman, all of which are generally discharged from their respective pieces with the same commencing velocity, have a shorter range, as the size of the projectile is less. Even water is sometimes thrown from a gun or powerful syringe to stun birds, that they may be obtained with uninjured plumage; but it soon divides in the air so minutely that it reaches only to a short distance.

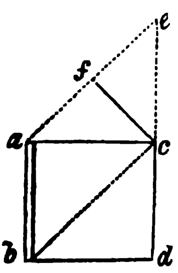
Water falling through the air from a great height, goes on suffering a gradual division into smaller and smaller portions, which at last may be said to be nearly all surface; and then the resistance of the air lets them fall very slowly indeed. The relation of the size and resistance is well shown by the difference of celerity in the descent of a minute fog, a drizzling mist, and common rain. The toy called the *water-hammer*; is merely a little water enclosed in a tube exhausted or empty of air. When the water is made to fall from one end to the other, as there is no air to impede or divide it in its descent, it falls as one mass, and makes a sharp noise like the blow of a hammer. —The same law explains why a spider's thread or a single filament of silk floats so long in the air before it falls;—why there is almost constantly suspended in the air, wherever active man resides, that immense quantity of very minute solid particles, which, when rendered visible by the sun's light passing directly through them, are called motes in the sunbeam—particles which are constantly settling on household furniture, and rendering necessary the daily operation of dusting or cleaning;—why the fine dust sent aloft during the eruption of volcanoes is often carried by the wind to a distance of hundreds of miles;—why in the deserts of Africa the strong winds often transport fine sand from place to place, overwhelming caravans, and forming new mountains, which succeeding blasts are again to lift;—why in the bottom of a river, or in a tides-way, fine mud is found where the current is slow; sand where it is quicker; pebbles, or large stones, where it is quicker still; while in rapids and water-falls, only massy rocks can resist the fluid force. Now rock, pebble, sand, and mud may all be the same material in portions of different magnitude.

This law explains the operation of *levigating*, by which substances insoluble in water are obtained in the state of a very fine powder. Any such substance is first ground or powdered in the ordinary way, and mixed with water. The grosser parts then soon fall to the bottom, while the fine dust remains longer suspended. This is afterwards obtained separately, by pouring the liquid which bears it into another vessel, and allowing more time for the slow subsidence. The fine powder of flint used in the manufacture of porcelain is obtained by levigation; as is also that of calamine stone, and other powders used in medicine and various arts.

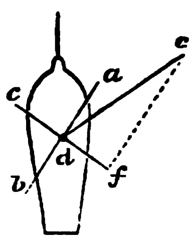
This law further explains how, by means of air or water, bodies of different specific gravities, although mixed ever so intimately, may be easily separated. If pieces of cork and lead be allowed to fall through the air together, the lead will reach the ground first, and may be swept away before the cork arrives: in a vacuum the whole would fall together, as proved by the common experiment of the guinea and feather falling in the exhausted receiver of an air-pump. Again, when a mixture of corn and chaff, as it comes from any threshing machine, is showered down from a sieve in a current of air, the chaff being longer in falling is carried far by the wind, while the heavier corn fall almost perpendicularly. The farmer, therefore, by *winnowing* in either a natural or artificial current of air, readily separates the grain from the chaff; and, if he desire it, may even divide the grain itself into portions of different quality. Similar to the operation of separating chaff from corn by wind, is that of separating sand or mud from gold-dust by water:—the soil containing gold-dust is first spread on a flat surface, over which a current of water is then made to pass; which current carries away the lighter rubbish, and leaves the gold. If a mass of metal be affixed on the end of a rod of wood, this, whether simply falling through the air, or advancing as an arrow, will follow the heavier metal as its point. The cork of a shuttlecock is always foremost for the same reason.

The instances enumerated under this head serve to show how many and varied the results may be which flow from a single principle.

When a fluid and a solid meet each other, whatever be the obliquity of their approach, the impulse or effect is always perpendicular to the surface of the solid, but is less forcible as the obliquity of the approach is greater.



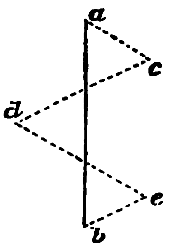
Suppose *a b* to represent the edge of a board or of any flat smooth surface, a fluid approaching this surface, in whatever direction, must act upon it as if approaching perpendicularly, because, on account of the smoothness, the fluid, although coming obliquely, can take no hold of it to push it endways, either towards *a* or *b*. Again the impulse of a stream acting on the surface will be less forcible if it be oblique, both because less fluid will touch, and because the velocity of the approach will be less. The line *c d* marks the breadth and therefore force of a direct stream reaching the board; and the shorter line *f c* marks the smaller breadth that can touch it, of a stream coming obliquely in the direction *c b* in the oblique stream, moreover, if the line *c b* mark the whole velocity, the shorter line *c a* will mark the slower rate of approximation to the board, and therefore will show the loss of force on this account from the obliquity of action. (This subject was treated of at page 100, under the head of *Resolution of Forces.*)



Hence the wind blowing upon the sail of a ship, however obliquely, always presses it directly forward or perpendicularly, as regards its surface; but acts less forcibly as the obliquity is greater. If the wind be represented, as to direction and strength, by the line *e d* approaching the sail *a b*, it will act on the sail as if it came from *f* to *d*, or as if the sail were pulled by a rope *d c*. We see in this, how a ship can be made to sail in a certain degree against the wind; for all the sails being adjusted so as to receive the wind in the direction here shown, they all act to produce the same result as if ropes were pulling from each in the direction *d c*.

The reason again why a rope like *c d* pulling sideways as well as forwards—as instanced in a tow-rope from a canal boat, makes the vessel advance rapidly forward, but scarcely at all sideways, is, that vessels are formed to pass forward at least twenty times more easily with their sharp bow, than sideways with their long broad keel; and therefore a force that were pulling equally sideways and forwards, would make a ship advance twenty miles in the direction of her keel, that is forwards, for one mile which she would deviate sideways.—The deviation sideways, which in sailing vessels must take place to a certain extent whenever the wind is at all oblique, is called the *lee-way*.

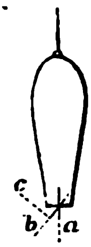
A vessel having to sail from *a* to *b*, while the wind blows directly against her course from *b* to *a*, is obliged to sail *close to the wind* as represented in last page, first perhaps to *c*, as represented by this figure, with the right or starboard side to the wind, then to *tack*, as it is called, or turn round, at *c*, and to sail to *d*, with the left or larboard side to the wind; then to go on the starboard tack again to *e*, and from thence to the port at *b*.



In making way against a *contrary wind*, the sails of a ship are pointed so nearly edgeways to the wind, that unless very flat, a great portion of their surface becomes useless. The Chinese manner of rigging is, in this respect at least, superior to the European; for in it bamboo reeds attached across the sails render them as flat as boards. When a Chinese ship has her sails pointing edgeways to a spectator, he only sees the masts which support them.

The reason why a ship generally sails faster with the wind from one side, than when it is from directly astern, is, that in the former case all the sails are acting, although individually not to the best advantage, while in the latter, the sails in front are becalmed by those behind them. A ship with a side-wind may move faster than the wind, as is often true of the outer extremities of a windmill's vanes.

The law now under consideration explains the action of the *rudder* of ships,—that contrivance, by which a single steersman can direct the course of a mighty vessel through rocks and shoals, more steadily and safely, than the most adroit charioteer can guide his vehicle. The helm or rudder is a projection from the stern-post of the ship, turning on strong hinges, in the manner of a door or gate, and moved by a beam or lever called the *tiller*, proceeding forwards to where the steersman stands. In small vessels the tiller is above the deck, and the steersman applies his hand directly to it; but in large ships it is below, and



is moved by ropes rising from it to *the wheel* on the deck, where the steersman stands with the compass before him. While the rudder points directly astern, as to *a*, like a continuation of the keel and stern-post, it does not affect the vessel's course; but if it be inclined ever so little to one side, as to *b* on the left, or *larboard* side, the water immediately acts on it in the direction *c b*, perpendicular to its surface, and pushes the stern to the right or starboard side,—an action equivalent to pulling the bow to the left or larboard.

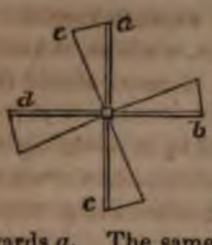
It is possible to make a ship or boat steer itself, by having a powerful vane on the mast-head, connected with the tiller-ropes by two projecting arms from its axis. If desired to make the ship sail directly before the wind, the tiller-ropes would be fixed to the vane so that the helm should be in the middle position, when the vane were pointing directly forward; and should the vessel then from any cause deviate from her course, the vane by its changed position with respect to her, would have produced a corresponding change on the position of the helm, just such as to bring her back to her course. It is evident that by adjusting such a vane and rudder to each other in different ways, any desired course might be obtained, and which would alter only with the wind. The vane would require to be of large size to have the necessary power; a wide hoop, for instance, with canvass stretched upon it; and the rudder, that it might turn with little force, would be hung on an axis through its middle, instead of as usual, by hinges at one edge. Cases have occurred were ship-wrecked persons might have sent intelligence of their disaster to a distant coast, by a small vessel, or even a block of wood fitted up in this way; and the method might sometimes save an additional hand in a boat's crew. It admits also of other applications, particularly in war.

As fluids act on surfaces, in a direction perpendicular to them, the water on the right side of a ship's bow is always pressing towards the left side; but owing to the equivalent and contrary pressure there, the ship holds her course evenly between the two, or straight-forwards. When a ship however owing to a side wind, lies over or *heels*, as it is called, that side of the bow which sinks most in the water is more pressed than the other; and were it not for a counteracting inclination of the rudder then made, constituting what is called *weather helm*, the ship's head would come round to the wind. Now ships so rarely have the wind exactly astern, that to diminish the almost constant necessity for *weather helm*, the masts, and consequently the mass of the sails, are placed more towards the bow than the stern.

Because the bow of a ship is oblique downwards as well as sideways, the water, when she moves, is constantly tending to lift the bow; hence when a vessel is dragged by a low horizontal rope, as in the case of a boat attached to a sailing ship's stern, or is moved by paddle-wheels, like steam-boats, the bow rises much out of the water, and the stern sinks in the hollow or furrow of the track; but when she is driven by sails, as these are high on the mast, and are acting therefore on a long lever to depress the bow, the two opposing tendencies just balance each other, and the vessel sails evenly along.

The form of the fore part of a ship has less influence upon her speed of sailing, than the form of the part from the middle to the stern, called the *run*. When a ship is at rest, there is of course as much forward pressure of the water about the stern as of backward pressure on the bow; but when she sails, she is running away from the propelling pressure behind, and is increasing the resisting pressure in front. A gradual tapering of the hind part therefore, or a *fine run*, as it is called, which allows the water to apply itself readily to it, as it passes along, must quicken much the rate of sailing. A tree, or the tapering mast of a ship, can be drawn through the water the most easily with the large end foremost.

The *common windmill* furnishes another illustration of the action of fluids on oblique surfaces. The face of the windmill is turned directly to the wind, but the four flat vanes or sails of



which the great wheel consists are individually oblique. Thus the edge *a* of the vane *a e*, is more forward as regards the coming wind or a spectator in front, than the edge *e* and the action of the wind therefore, being perpendicular to the oblique surface *a e*, pushes it in a degree towards *a*. The same remark applies to each of the other vanes where the edges *b*, *c* and *d* are in front, and those marked by the fainter lines are behind; so that each vane produces an equal effect in turning the wheel. The law of the "decomposition of forces," explained at page 100 tells in what proportions the force of the wind is exerted to push the wheel backwards against it supports, and to turn it round.

Windmills were first used in Europe in the fourteenth century. They are still of great importance in countries where there are no water-falls and little fuel for steam engines. In some of the richest European landscapes, every height is crowned by its busy windmill, grinding corn, or sawing wood, or pressing oil-seeds; and over the plains, similar wheels are made to pump water for domestic use, or incessantly to drain the land.

The smoke-jack of our chimneys is a small windmill, driven by the ascending current of air in the chimney.

The feathering of an arrow acts in part on the principle of the windmill. The feathery projection from the shaft is not quite straight, but winds round it a little, like the thread of a screw; and the arrow therefore, by constantly turning as it flies, goes straight to its object although the shaft itself be bent, because any deviation is constantly correcting itself.

It might be supposed that a wheel, which the wind turned by *direct* action on the rim, as water turns common water-wheels, would be preferable to the windmill-wheel now described which is turned by *oblique* action on the face: accordingly, a wheel like a water-wheel only with broader vanes, has been placed in a house or cover, so that one side at a time was exposed to the wind;—but it is a powerless machine. The oblique-vaned wheel applies to use only half perhaps of the force of the air which reaches it, but its wide expanse receives a stream of air often of thirty feet in diameter, while an ordinary window would admit enough for a wheel of equal size of the other construction.

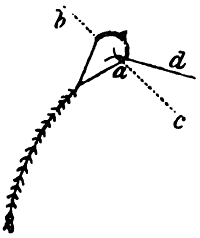
There are some situations where it would be an advantage to have water-wheels like the common windmill-wheel, *viz.* where the stream is sluggish, and is deep enough to allow a large wheel to be wholly immersed.

A small wheel with broad oblique vanes has been used as a means of ascertaining the rate of a ship's sailing. It is allowed to drag a-stern, in the water; and the number of revolutions made in a given time marks the ship's speed.

A windmill-wheel made to turn during a calm by force applied to its axle, would be pressed endways or in the direction of its axle, just as if wind were blowing upon it, owing to the re-action of the still air, through which its oblique vanes were made to sweep. Such a form of wheel fitted to work in water, and called a water-screw, has been applied at the bow or stern of steam-boats, to propel them in canals where there was no room for side wheels. But as from the obliquity of the surfaces only part of the applied power becomes propulsive—the remainder being wasted in the lateral strain or twisting of the water—the method is not applicable to general purposes.

Two small windmill-wheels placed horizontally one above the other, on the same axis, and made to turn in opposite ways by springs or otherwise, would rise in the air, carrying a certain load with them, and would constitute, therefore, a flying machine.

A *paper kite* rises in the air for the same reason that a windmill vane turns. Its cord *d* is attached to it above the middle of its loop, and therefore so as to make it present always an oblique surface to the wind; and by the action of the wind perpendicular to its surface, it rises as if pushed up in the direction *c a*, or as if drawn up in the direction *a b*.—A kite might be made large enough to lift a man.



Cats have been sent up at kite's tails, and have fallen down safely under parachutes from the greatest elevations. It might be safer for a man to rise at a kite's tail to reconnoitre an enemy's position, or to survey an unknown country, than under a balloon, as was practised by the French during the revolutionary wars. He might have the security of a parachute, and the power of regulating the obliquity of attachment of the rope, so as to command his ascent or descent at pleasure. An exhibition has lately been made (October 1827) of a car drawn along the highways by kites. That they might ascend to a great elevation, where the wind is generally stronger than below, they were attached to each other in a row, so that the second kite mounted as if its cord were held by a hand at the first, the third as if rising from the second, and so forth. The projector of this novelty hoped that he had pointed out a most valuable means of travelling across extensive plains, sandy deserts, tracts of snow, &c., and, in all cases, nearly with the speed of the wind.

The effect of a single oar, used to propel a boat or vessel, in the manner called *sculling*, is referrible to the law now under consideration. The oar or scull rests on a round-headed prop or nail at the stern, and is made to vibrate from side to side. In all its positions it has the surface which presses the water, turned obliquely backwards; hence the re-action of the water propels the boat.—In China, large vessels are moved, by a single sculling oar which half the ship's company may be urging at the same time. A sculling oar may be regarded as a single vane of such a propelling wheel as above described, made to sweep across, behind the vessel, alternately to the right and to the left.

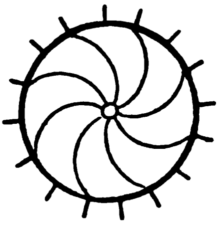
The action of a fish's tail, and of the bending of an eel or snake in water, resembles that of the sculling oar. Many people believe that the tail of the fish is only the rudder of the body, as is true of a bird's tail, but it is in fact the great instrument of motion, while the fins are chiefly used to steady and direct the motion.

"Fluids lifted in opposition to gravity." (*See the analysis, page* 371.)

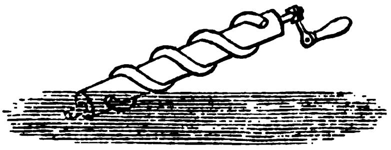
Water, as we have seen in former parts of this work, is to the living universe, nearly what the blood is to the animal body, and a constant supply and circulation are required. This has been provided for to an extraordinary extent, by the operation of natural causes; but for many purposes of human society, water is still required where there is no natural supply. A great variety of means have been employed for raising it, some of which, sufficient to illustrate the whole, are now to be considered.

Water may be raised in a bucket attached to a rope pulled up by the hand; or the rope with the bucket may be wound round a barrel or axle turned by a winch.—There may be a succession of buckets on a rope, rising one after the other, and when emptied, descending again on the opposite side of the wheel or axle which lifts them: the rope to which they are attached being a circle or *endless rope*, and constituting with them what is called the *bucket-machine.*—Instead of buckets, on such an endless rope or chain, there may be a succession of flat pieces of wood, which, on being drawn up through a large tube or barrel, like loose-fitting pistons, will raise a copious stream of water: forming the contrivance called the chain-pump.—Or simply an endless rope of hair, very rough, passing round one wheel above and another below, may be whirled quickly by turning the upper wheel, and a mass of water adhering by friction to its rising half, will be thrown into a reservoir at the top where it passes over the upper wheel: several such ropes may be joined side by side to increase the effect.—But the most important of all water-raising engines are the *lifting and forcing pumps*, already described at page 307. They are used to draw from wells, to drain mines, to send a supply over cities from low sources, to pump ships, to throw water for extinguishing fires, &c.

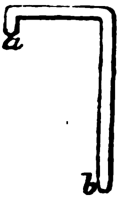
A stream of water passing through a garden, or in the midst of fields, may give beauty without utility, unless it can be employed to irrigate the vegetable creation around. In the fields and gardens of Persia, where the heat of the sun is very intense, the streams are ingeniously caused, by their own action, to lift a part of their water into elevated reservoirs, from which it again flows in sloping channels to wherever it is required. A large water-wheel is placed so that the stream may turn it, and around its circumference buckets are attached, to be filled as they sweep along below, and to be emptied into a reservoir as they pass above—or instead of buckets, the spokes of the wheel are themselves made hollow, and curved as here represented, so that as their extremities dip into the water at each revolution, they receive a quantity of it, which runs along them as they rise, and is discharged into a reservoir at the centre. These are called *Persian wheels*, but they are in common use on the banks of the Nile, and elsewhere.



A pipe wound like a screw upon a sloping barrel, and made to dip its lower mouth into water at each revolution of the barrel, will also raise water: the lower portions of the turning pipe will always be full of it, and it will be rising in them to the top, as if on an inclined plane. Archimedes was the inventor of this beautiful water-screw, and has left his name to it. It may be turned by hand, or by a passing stream which acts on the vanes of a water-wheel affixed upon it.

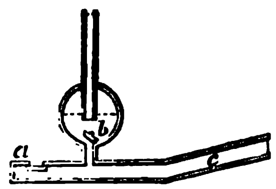


Water may be raised by producing centrifugal force at the upper end of a bent pipe dipping into a reservoir. Supposing the pipe to be bent as here represented, and the horizontal arm *a* to turn like the spoke of a wheel, while the upright portion remains steady like an axis,—if the pipe be once filled with water, it will continue to throw out a constant stream from the end *a*. To increase the discharge there may be



several horizontal arms from one larger upright pipe, all emptying themselves into a circular trough or reservoir; and to prevent the necessity of refilling the pipe after every interruption of its motion, a valve opening upwards must be placed at the bottom. This contrivance has been called the *centrifugal pump*, because the water is raised at *b* as in a pump, by the pressure of the atmosphere, to supply the place of that which is thrown out from *a* by the centrifugal force. The velocity of rotation must bear proportion to the height of the discharging aperture *a* above the surface of the water in the reservoir.

It had long been observed in household experience and elsewhere, that while water is running through a pipe, if a cock at the extremity be suddenly shut, a shock and noise are produced there. The reason is, that the forward motion of the whole water contained in the pipe being instantly arrested, and the momentum of a liquid being as great as of a solid, the water strikes the cock with as much force as if it were a bar of metal or a rod of wood having the same weight and velocity. A leaden pipe, if of great length, is often widened or burst in this experiment.—lately this forward pressure of an arrested stream has been used as a force for raising water, and the arrangement of parts contrived to render it available has been called, on account of the shock, the *water-ram*. The ram may be described as a sloping pipe in which the stream runs, having a valve at its lower end, to be shut at intervals, and a small tube rising from near the end towards a reservoir above to receive a portion of the water at each interruption of the stream. Now in a pipe ten yards long, two inches wide, and sloping six feet, water allowed to run for one second acquires momentum enough to drive about half a pint, on the shutting of the cock, into a tube leading to a reservoir forty feet high. Such an apparatus, therefore, with the valve shutting every second, raises about sixty half-pints or four gallons in a minute. The valve is ingeniously contrived so that the stream works it as desired. In this figure which represents the lower



end of the water-ram, *a* is the opening by which the stream escapes from it, and the valve or flap seen below the opening is that which by suddenly shutting arrests the stream. The valve is made so heavy, that the stream must run for a certain time to acquire force enough to shut it; and in the instant of its shutting, a little of the advancing water passes upwards through the valve *b* towards the reservoir. The water in the main pipe then becoming stagnant again, has no longer power, by its weight alone, to keep the valve *a* shut: this, therefore, falls open and the stream begins again; again to be arrested as before; and as long as the supply of water lasts, the action of the apparatus continues. The action of a water-ram may be compared to the beating of an animal's pulse. The upright tube is made wider at the bottom where it first receives the water, so as to constitute there an air vessel *b* (described at page 290,) which by the air's elasticity converts the interrupted jets first received into a nearly uniform current towards the reservoir. The supply of air to this vessel is maintained by the contrivance called a *snifting valve.*

In the proceeding pages on the doctrines of fluidity, we have had to touch on many of those phenomena of nature and art which are the most important to man; yet we have seen how beautifully simple and intelligible they are all rendered when referred by a methodical arrangement to the few fundamental truths. Each one of the many particulars belonging to this head, which when explained appear so obvious, has yet been a distinct step in the slow progress of discovery or invention, and probably when first understood has filled some ingenious mind with intense and purest delight.

PART III.

SECTION IV.—ACOUSTICS, OR PHENOMENA OF SOUND AND HEARING.

ANALYSIS OF THE SECTION.

1. *Sound is heard when any sudden shock or impulse is given to the air, or to any other body which is in contact directly or indirectly with the ear.*
2. *If such impulses be repeated at very short intervals, the ear cannot attend to them individually, but hears them as a* CONTINUED SOUND, *which is* GRAVE *or* SHARP, *according as the impulses are few or many in a given time: and all continued sound is but a repetition of impulses.*
3. *When the number of impulses producing some continued sound has a simple relation, as of half, third, fourth, &c. to the number producing some other sound which is heard either simultaneously with it, or a little before or after, the ear is generally much and pleasingly affected by the circumstance; and such sounds are said to have* MUSICAL RELATION *to each other, or to be* CONCORDS, *while all others are termed* DISCORDS.
4. *The shock which causes the sensation of sound* SPREADS *or is propagated in all bodies somewhat as a wave spreads in water, with decreasing strength as the distance increases, but with a velocity nearly uniform, and which in air is 1,142 feet per second.*
5. *Sound is* REFLECTED *from smooth surfaces, and hence arise many curious and pleasing effects, called* ECHOES, *&c.*
6. *The structure of the ear illustrates the laws of sound.*

Early inquirers into nature had remarked that in most instances of noise or sound there was present a shock or trembling of the sounding body, often visible, but sometimes only sensible to the touch, or discoverable by other effects. It was noted in the string of a harp, the reed of a haut-boy, the prongs of a tuning-fork, the lip of a bell. But it was reserved for the moderns to understand fully, that the animal organ called the ear, is merely a structure of parts admirably adapted to be affected by the concussions or tremblings of things around; and that sounds in all their varieties are merely such motions, affecting the ear through the medium of the air which surrounds us, or of some other body or series of bodies reaching from the trembling thing to the ear.

The delicacy and complexity of an organ destined to feel and to distinguish such slight and varying influences, and the unspeakable importance of it to man, as that which makes him capable of using language, besides being his ever-watchful monitor of surrounding occurrences, the channel by which the fascination of music enters, &c., render this subject, to all who love to read in nature the attributes of its author, a most favourite study.

Because all the bodies around us are immersed, in common with ourselves, in the ocean of air which covers the earth, we are much more frequently warned of the shocks and tremblings of which we have been speaking, by their effect on the air, than in any other way; hence the early prejudice that air was necessary to sound, and hence the reason why the doctrines of sound have generally been accounted a part of pneumatics. We shall now find, however, that all bodies convey those tremblings, and that air in many cases is neither the quickest nor the best carrier. Although our notions on the subject are thus corrected, it is still convenient to consider the doctrines of sound in this place.

1. *" Sound is heard when any sudden shock or impulse occurs in a body having communication, by the air or otherwise, with the ear. (Read the analysis.)*

Common instances of a single impulse are—the blow of a hammer—the clap of hands—the crack of a whip—a pistol-shot—any explosion—the thunder-clap.

The loudness of sound conveyed by air depends on the air's density. A bell enclosed in the receiver of an air-pump is heard less and less distinctly as the air is exhausted, and in a vacuum is not heard at all.—Even the blow of a hammer in a vacuum is not heard if care is taken to prevent the shock from being communicated through neighbouring solid bodies.—In the by stopping the current of air for an instant at each vibration, produces a repetition of pulses, or sound. Elastic rods simply resting on supports at both ends; or suspended by their middle, will also vibrate: a musical instrument is thus made of pieces of glass laid upon two strings, and struck by a cork hammer: in the island of Java, a rude instrument of the same kind is made of blocks of hard elastic wood.—The half of a hollow sphere of elastic metal very readily takes on a vibration, during which its form is constantly changing from the perfect round to the oval and conversely; there is consequently repeated percussion of the air, and a continued sound, and the thing is called a *bell.* A bell admits of variety of shape, and may be made of any elastic substance, as metal, glass, earthenware (buyers ring earthenware to ascertain its soundness,) and even of hard wood.—The *Chinese gong* is a metallic vessel shaped like a common sieve, having a manner of vibration very peculiar, and producing sounds that are rousing and sublime. The *drum* has a tense elastic membrane on which the blows of the drumstick are received: its tone ceases quickly, because the motion of its broad surface is much resisted by the air.—In the flute, flageolet. organ-pipes, &c. the air is forced through narrow passages, and is divided by sharp edges, in a way to suffer constant but perfectly regular condensations or interruptions sufficient to affect the ear; and hence the endless variety of sweet continued sounds which these contrivances are known to produce.

To the perfection of a tone, it is of no consequence in what way the pulses of the air are produced, provided they follow with sufficient regularity: witness the pure sound produced by the motion of a fly's wing—supposed by many to be the voice of the insect. The clacking of a cornmill, and the noise of a stick pulled along a grating, are not musical, only because the pulses follow too slowly.

Where a continued sound is produced by impulses which do not, like those of an elastic body, follow in regular succession, the effect ceases to be a clear uniform sound or tone, and is called a *noise.*—Such is the sound of a saw or grindstone—the roar of waves breaking on a rocky shore, or of a violent wind in a forest—the roar and crackling of houses or of a wood in flames—the mixed voices of a talking multitude—the diversified sounds of a great city, including the rattling of wheels, the clanking of hammers, the voices of street-criers, the noises of manufactories, &c.: which rough elements, however, at last mingle with such uniformity, that the combined result is often called the hum of men, from analogy to the smooth mingling miniature sounds which constitute the hum of a bee-hive.

" Grave and sharp sounds." (*See the analysis.*)

The difference of sounds, which depends on the different number of vibrations in a given time of the sounding body, divides them into classes: called *bass*, *low*, or *grave* notes, for the slow vibrations; and *high shrill*, or *sharp* notes for those that are quick.

The frequency of vibrations in strings increases with their shortness, lightness, and tension—for if a string be long or heavy, there is a greater mass of matter to be moved, and hence a slower motion; and if a string be slack, the force of elasticity; which pulls it from any deviation, back to the straight line, is so much the less. It is found that a string of half a given length, or of one-fourth of a given weight, or of quadruple tension, vibrates twice as fast on any one of these accounts.

These truths are familiarly illustrated in the violin. The low or bass string is thick and very heavy from being covered with metallic wire, and the others gradually diminish in magnitude and weight, up to the smallest or treble. They are tuned to each other by being attached to pins, which, by turning, increase or diminish their tension; and the sound produced by each may be afterwards varied to a great extent, by pressing different parts of it with the finger against the board, so as to shorten the vibrating portion.

An analogous law, as to the influence upon tone, of weight and dimension, holds with respect to bells, glasses, reeds, &c., and enables us to use these in the construction of musical instruments.

3. " *When the number of impulses producing some continued sound has a simple relation, as of half, third, fourth, &c. to the number producing some other sound which is heard either simultaneously with it, or a little before or after, the ear is generally much and pleasingly affected by the circumstance; and such sounds are said to have musical relation to each other, or to be concords, while all others are termed discords.* (*Read the analysis, page.* 402.)

Understanding now that all continued uniform sounds are produced by a repetition of similar beats or vibrations, we perceive that in the series from grave to sharp, there must be such as, with respect to the number of beats in a given time, are related to each other, as 1, 2, 3, 4, &c., or, which is the same thing, as 10, 20, 30, 40, &c. Now as between two sounds, one of which has 20 beats, while another has 10, there must be a coincidence at every second beat of the quicker, and between sounds whose beats are to each other as 30 to 20, there must be a coincidence at every third beat of the quicker, and so forth; we should naturely expect the ear to be differently affected by such correspondence, than when the coincidence is either less frequent, or is irregular. Accordingly we find that all sounds which have simple relations to each other, are remarkably agreeable to the ear, either when heard together, or in close succession; while those in which the coincident beats are farther apart, are heard with indifference, or are felt to be positively harsh and disagreeable.—It is a fact meriting notice here, that the coincident or double pulses of any two concordant sounds become the elements of a third sound, which is always heard with them, and is called their *grave harmonic.*

If a long musical string be made to sound, and the number of its vibrations in a given time be ascertained, we find that half of it used as a whole will vibrate twice as fast; a third part, three times as fast; a fourth part, four times as fast; and so on, producing the sounds or tones most nearly related to each other. A fine illustration of this is afforded by the string of a violincello, when made to vibrate by moving a bow very gently across it, near the bridge; there are then heard not only the sound or note belonging to the whole length of the string, but also, more feebly, the subordinate notes belonging to its half, its third, its fourth, &c. beautifully mingling with the first sound, and forming with it a rich harmony. Often in such a case the subordinate sounds swell with such force as to overpower for a time the fundamental note; and then, if the string be carefully examined, it will be found to be vibrating, not as a whole, but in two, three, or four distinct portions, with points of rest between them, on which points little bits of paper thrown will remain, but will be shaken off from every other part. The same harmonic sounds may be produced, while drawing the bow across the string, by touching the string lightly with the finger, at the points where we wish it to divide.

The sounds thus belonging to a single cord or string, and produced by its spontaneous division into different numbers of equal parts, constitute, when heard together, or in succession, the simple music of nature herself. It is produced pleasingly, as just described, by the single string of a violincello; but in the most perfect manner by the instrument called the Æolian harp.

The Æolian harp is a long box or case of light wood, with harp or violin strings extended on its face. These are generally tuned in perfect *unison* with each other, or to *the same pitch* as it is expressed; but when the harp is suspended among trees, or in any situation where the fluctuating breeze may reach it, each string, according to the manner in which it receives the blast, sounds either entire, or breaks into some of the simple divisions just described; the result of which is the production of the most pleasing combination and succession of sounds that ear has ever listened to or fancy perhaps conceived. After a pause this fairy harp is often heard beginning with a low and solemn note, like the bass of distant music in the sky: the sound then swells as if approaching, and other tones break forth, mingling with the first, and with each other. In the combined and varying strain, sometimes one clear note predominates and sometimes another, as if single musicians alternately led the band: and the concert often seems to approach and again to recede, until with the unequal breeze it dies away, and all is hushed again.—It is no wonder that the ancients, who understood not the nature of air, nor consequently even of simple sound, should have deemed the music of the Æolian harp supernatural, and, in their warm imaginations, should have supposed that it was the strain of invisible beings from above, descended in the stillness of evening or night to commune with men in a heavenly language of soul intelligible to both. But, even now that we understand it well, there are few persons so insensible to what is delicate and beautiful in nature, as to listen to this wild music without emotion; and to the informed ear it is additionally delightful, as affording a fine illustration of those laws of sound which human ingenuity at last has traced.

As the simple scale of sound, called the *major chord*, which nature thus gives by the spontaneous dividing of a single string, has considerable vacancies in it, human taste or feeling, long before there was any theory of music, had joined to the notes of a chief chord those also of another chord a little sharper or more acute, and those of another a little more grave, of which additional notes, while part agreed, or were in unison with certain tones of the principal chord, the remainder just served to fill up its larger intervals, and to complete a scale of nearly uniform intervals, as three ladders having unequal intervals between their steps, might still, if placed together, complete a stair of easy ascent. The relation between the chords is the same as would exist between ladders similarly divided, but of which the middle or principal were only two-thirds as long as the longest, and the shortest were only two-thirds as long as the principal. So truly natural is the scale thus formed, that it has arisen in all nations, however remote or unconnected; and an untutored individual, in attempting to raise his voice by regular steps, falls into it almost as readily as the learned professor. The scale has eight steps or notes, between any principal or fundamental tone, and the tone above it vibrating twice as fast, or the tone below it vibrating half as fast: these two tones or notes are hence called the *octaves* above and below the *key note*, and the intermediate notes which fill up either octave, are distinguished by the names of *second*, *third*, *fourth*, &c. The numbers which express the relations of beats among the notes of an octave are easily found, from our knowing the relative number of beats in the notes of any one simple chord, and our knowing that in the compound scale of three chords, the corresponding notes of the higher beat thrice for twice of the principal, and the corresponding notes of the principal beat thrice for twice of the grave cord. the following is the arithmetical expression for the notes of an octave, 1 $\frac{9}{8}$ $\frac{5}{4}$ $\frac{4}{3}$ $\frac{3}{2}$ $\frac{5}{3}$ $\frac{15}{8}$ 2. The scale however far extended, is a repetition of similar octaves, so that any note in it vibrates just twice as often as the corresponding note in the octave below, and half as often as that in the octave above. The lowest note which is perceptible to the human ear has about thirty beats in a second, and the highest, about thirty thousand; and there is included between these two, a range of nearly ten octaves. To certain ears the extremes of this range are inaudible or inappreciable. Some persons do not hear at all the sharp note of the grasshopper, while some cannot distinguish among the lowest tones of an organ or piano; and yet to all, the perception of intermediate sounds may be very perfect. Few musical instruments comprehend more than six octaves, and the human voice in general has only from one to three, the male voice being in pitch an octave lower than the female.

If the intervals in the musical scale were all equal, a performer might choose indifferently any note as a fundamental or key note, and would only have to attend to the number of intervals above and below; but, in fact, the third and seventh intervals in ascending from a key note are only about half as large as the others. It is owing to this circumstance that in changing the key on any instrument, certain notes belonging to other keys are half a note too *flat* or too *sharp*, and must be changed accordingly. It is on this account that when an instrument is used to play in all keys, its larger intervals must be divided into two parts. The fact of unequal intervals, ill understood, is what gives an appearance of great complexity and difficulty to musical science.

Melody, in music, is when notes having the simple numerical relations of beat which we have been describing are played in succession: *Harmony* is when two or more such notes are sounded together. The effect of both is delightfully increased by making the duration of the notes or strain correspond with certain regular divisions of *time*. This gives to the ear a prescience, to a certain degree, of what is coming, with the pleasure of having expectation realized, as it is by the metre and rhyme of poetry: it also enables the memory to retain musical combinations of sound—for the airs of the Æolian harp, which observe no *time*, cannot be repeated. The music of a single drum is that of time only.

Melody, *harmony*, *time*, and *varying intensity of sound*, are the four constituents of music, and it seems that almost every state of mind has, in some combination of these, an appropriate expression, intelligible to the general feeling of the human race. The exact relation between the movements of the animal spirits, as it has been expressed, or the fluctuating stream of excited feeling, and the varying flow of sound in a musical composition, is not well understood, but the fact of their correspondence and its consequences are most remarkable. Under many circumstances, the association between the feeling and the expression is so strong, that the latter is often spontanoeusly betraying itself;—witness the almost constant humming, or low song, of some contented beings—the singing and whistling of careless childhood, or of the light-hearted rustic who lives among the beauties of nature—the heart-rousing strain of the hunter or warrior—and the tender expression of many of the modifications of anxiety and sorrow.—The musical sensibilities are by no means limited to the human race, for where is there expression more exquisite than in the song of the nightingale during the evenings of spring, or of the thrush and blackbird, amid the quiet retreats of our woodlands?—and the music of these untutored songsters is made up of the same elements as our own.

The *accompaniment* of an air afforded to a singer by one or more instruments, and which is so pleasing, is chiefly the sounding simultaneously, in a subdued manner, some other notes of the chords to which the several vocal notes belong. *Duetts* and more complicated *concert-pieces* **have their** origin from the same source: and highly cultivated **musical sense** can even follow and enjoy several melodies played together.

Musical notes, by whatever instrument produced, have to each other the same numerical relations in the beats or vibrations which constitute them. The different qualities of tone, therefore, from different instruments, can only depend on the peculiarities of the single beats, as to whether they are sharp or soft, strong or weak, &c. Such is he extraordinary nicety of perception which the human ear possesses in this respect, that it can not only distinguish different kinds of instruments playing the same note, but different instruments of the same kind, even to the extent, for instance, of recognizing each one of a hundred voices singing the same air. One of the greatest charms of concert music, is that the voice and the different instruments may take up successively the parts of the strain suited to their individual expression—the flute and clarionet, for instance, breathe softness; the trumpet and drum arouse; the harp rolls out its brilliant chords; the violin leads the flowing sound through rapid and endless variety; and so of the rest.

That there might be correspondence in instruments when played together, and a known pitch when played apart, it became necessary to fix on some tone or number of vibrations as a point of comparison. Hence *tuning-forks* have been made with length of prongs calculated to produce some certain note; and when the note of the same name on any instrument is tuned in unison with this, the other notes can be easily adjusted according to the harmonic relations above explained.

Almost every substance or contrivance that can produce a uniform continued sound may enter into the composition of a musical instrument: hence the almost endless variety which the world has seen. The chief classes of instruments are *stringed instruments*, *wind instruments*, and *bells* or *rods*.

Of the stringed instruments, we may mention the *harp*, the *lyre* or *lute*, the *guitar*, the violin of all sizes, and the *piano-forte*. The harp, lyre, and lute, were the inventions of antiquity, and have brought down with them to the present times a thousand delightful associations. They awakened to inspiration the bards and poets of the young world, and they were the beloved companions of many of the noblest minds of succeeding times. Their great charm was in their power to heighten the emotions produced by music's twin sister, poetry; and the effects seem to have been magical.—The other instruments mentioned are of comparatively modern invention, particularly the pianoforte; and their perfection has assisted in carrying the *practice* of music to degress of complexity and difficulty, of which antiquity, dreamed not. It is a question, however, whether the style of the music now in vogue do not prove rather a degeneracy, than a desirable refinement of musical taste. Music is a language of nature, intelligible at once to all susceptible minds, and, in a degree, even to inferior animals; but modern art is attempting to make of it an artificial and conventional language, in which there may be fashion and change. The ornaments and accompaniments are now often so overwhelming, that the *melody*, in which the idea and sentiment really reside, is almost lost; and an unpractised ear, particularly if listening to an *organ*, often discovers only an unmeaning succession of chords. And when, in singing, the natural simplicity of melody is abandoned, in straining to execute with the voice the complicated movements which belong properly to instrumental accompaniment, the attempt destroys the poetry, by either rendering the words inaudible, or by sacrificing their natural expression to some supposed appropriate expression of the ornamental music. These considerations may account in part for the insensibility of so many highly endowed persons to what *is now called* excellent music. It must be allowed, however, that the changed state of society has also its influence, music being an appropriate expression rather of such high mental excitement as existed among the contentions, and uncertainties of the ancient Greek states, than of the calmer confidence and security which have come with modern civilization.—The tricks on the voice and on instruments, now so common, rank truly with tumbling and rope-dancing, and are no more natural music than the others are graceful gesture. And when we hear noted professors avow their inability to sing a simple ballad, or to play an unadorned melody, must we not conclude that the natural sense of music has left them, as the relish for nature's fare has left the morbid epicure.

The *guitar*, as affording an accompaniment to vocal music, has many advantages. It is not too loud, although the strains are distinct: it admits of very touching expression; it is very easily learned by all who should attempt to learn music at all; it is portable and cheap. The great facility of accompaniment on it depends on this, that the player is able by one position of the hand to touch the strings so that the sounds of all the six shall belong to the same chord:—three positions of the hand, therefore, for one key, produce all the notes and chords which a simple accompaniment requires; and the hand soon falls into these so readily, that the player is hardly sensible of exerting volition.

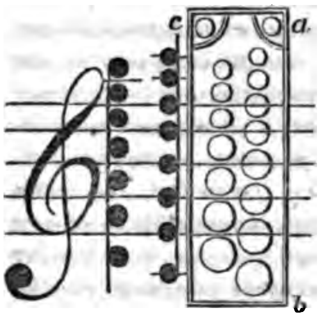
Wind instruments are, the *flute*, the *flageolet*, the *organ*, the *clarionet*, the *hautboy*, the *horn*, the *trumpet*, &c. The pitch or tone of a wind instrument, just as of a musical string, has relation to its length; and the vibrations causing the sound seem to be waves or condensations of air passing from the mouth to the extremity of the tube, and back again:—being more frequent, therefore, as the tube is shorter. It appears also, that on blowing more strongly, the air in the tube divides into separate vibrating portions, as a string may divide, and produces thus all the harmonic sounds belonging to the fundamental note. By blowing into a common German flute, for instance, it is possible to produce five ascending harmonics without moving the fingers at all. The music of a trumpet is limited to these five notes of the same chord; but in the flute, and other instruments with holes, the effective length of the tube is calculated from the upper end to the nearest hole left open; and each length has its harmonics.—The sounds of the human voice are the sweetest of all, and are produced by the vibrations of two delicate membranes situated at the top of the windpipe, with a slit or opening, called the *glottis*, left between them, for the passage of the air. The tones of the voice are grave or acute, according to the varying tension of these membranes, and to the size of the opening

In the *organ* there is a pipe for each note, and wind is admitted from the bellows to the pipes, by the action of keys, like those of a piano-forte. The organ may be played also very perfectly by a barrel, made to turn slowly under the keys, and to lift the keys in passing, by pins projecting from it at the required situations. Very complicated pieces of music are thus set on barrels, but at great cost of study and labour, and therefore of money: now a plain barrel, made to turn near the keys of an organ during performance on it by the hands, might be made to record with mathematical accuracy every touch of the most finished player, *viz.* by receiving marks of some kind from the keys as they were lifted:—to repeat with absolute accuracy, therefore, any performance, however delicate and exquisite, it would only be necessary to drive pins into the barrel where the marks remained, and afterwards to make these pins lift the keys. The author does not know that this idea has ever been acted on, or indeed has ever occurred before.

Bells are often conjoined in sets, having the musical relations, and to some persons their music is very agreeable. There are a loudness and solemnity in the tolling of a single bell which makes it a fit accompaniment of funeral rites.

The *Chinese gong* partakes of the nature both of a bell and of a great drum, and has something in its sound which is singularly affecting. In its own country it bears a part in one of the most imposing ceremonies which man has ever imagined. On certain festivals, as the sun is sinking in the west, the whole population of China,—a host of more than a hundred millions, —issues forth, under the single canopy of heaven, to testify, amid the thunder of gongs and the continued discharge of fireworks, that adoration and gratitude towards the Deity, which human nature, in all ages and climes has felt to be due and has eagerly sought to express, however blind as to the sublime simplicity of religious truth.

Bells or *goblets* of glass sound still more perfectly than those of metal, and by gentle friction on their edges with a bow or the wetted finger, their tones may be continued for any length of time, and may be made to swell and diminish like the human voice or the notes of a violin. A set of glasses, therefore, attuned to each other, according to the harmonic scale, becomes for certain species of music, the most perfect of all instruments. It is in fact an Æolian harp at command. Dr. Franklin, who first constructed a set, doubled the long line of glasses upon itself, and placed the half-notes as outside rows. The author, however, during some experiments on sound, found the *zigzag* arrangement here represented to possess many advantages. The small open circles represent the mouths of the glasses standing in a box *a b c*, and the relation of the glasses to the written musical notes is shown by the common music lines and spaces which connect them. The learner discovers immediately that one row of the glasses produces the notes written *upon* the lines, and the other row the notes written *between* the lines; and he is mentally master of the instrument by simple inspection. This arrangement also renders the performance easy, for the notes most commonly sounded in succession are contiguous; —and the relations of the notes forming a tune are so obvious to the eye, that the theory of musical combination and accompaniment is learned at the same time. The set of glasses here represented has two octaves, and with the additional *flat seventh* and *fourteenth*, seen at *a* and *c*, which when required, may be substituted for the corresponding glasses in the rows, it is capable of playing the greater part of our simple melodies. The player stands at the side of the box between *a* and *b*, and has the notes ascending towards the right hand, as in a piano-forte.



Musical ear.

Philosophers have not yet been able to account for a remarkable difference among individuals, as regards the perception of the musical relations of sounds. Many persons, without understanding any thing of acoustics, can tell instantly whether various notes heard together or in succession, have the relations to each other which we call musical, and which we now know to depend on the comparative numbers of beats in a given time; while others with an equally perfect sense of hearing can form no judgment on the subject. The former are said to have a *musical ear*, and the latter to want it; and although cultivation will raise mediocraty to considerable expertness, it cannot bestow the faculty where originally deficient.—Now there is on this subject a very common misconception, which proves a source of great mortification on one side, and of arrogance on the other, *viz.* that the possession of a musical ear, or the power of distinguishing notes, is the indication of all the finer sensibilities of the mind, while the want of it proves an opposite deficiency. Shakspeare's opinion of him "who hath not music in himself," is often triumphantly cited as applicable to all who want the distinguishing ear. The truth however, is, that many who signally excel in music are deficient in almost all else that humanity reveres,—witness the weak minds and disorderly lives of so many professed musicians,—while many again, who have no musical discrimination are otherwise examples of excellence, and even as regards sound, may be exquisitely sensible to other beauties and harmonies of nature. Such may not be deaf, for instance, to the music of spring, when all nature bursts forth in voice of rejoicing, nor to the awful music of the storm:—they may feel as music the silence of a lone wood, after being accustomed to the unceasing stir of multitudes—or, the stillness of night in a great city, where the astronomer contemplating the wondrous spheres above, hears only the tongues of passing time in the church-towers, or the call of watchmen, faintly sounding in the distance. Many excellent poets have had no musical ear.—The charm of music is often as much from early associations as from peculiar aptitude in the individuals: witness the effects so well known of the Swiss airs, when heard by native Swiss in foreign lands;—but, indeed, of the national melodies of all countries—it not being in nature, that at any period of life, or in any clime, a man should cease to deem those modulations lovely, which in his infancy and childhood he learned from a parent's voice—the mother's, perhaps, whose affection was so long around him as a shield, whose tears fell to chide his errors, and to reward where there was promise of virtue; whose steady judgment may have been his guide, whose faultless life his example, and who in all things to him may have appeared a personification of God's goodness on earth.

It is the prejudice with respect to musical ear and musical taste of which we are now speaking, that, in the present day, condemns many young women possessed of every species of loveliness and talent except that of *note-distinguishing*, to waste years of precious time in an attempt to acquire this talent in spite of nature, and yet, when they have succeeded as far as they can, they have only the merit of being machines, with performance, as little pleasing to true judges, as would be the attempt of a foreigner, who knew only the alphabet of a language, to recite pieces of expressive poetry in that language. Such persons, when liberty comes to them with age or marriage, generally abandon the offensive occupation; but tyrant fashion will force their daughters to run the same course. The waste of time now spoken of, is only one of many evil consequences which arise from the prevailing false notions with respect to music; but the subject cannot be farther pursued in this place.

"*The trembling which causes the sensation of sound spreads in all bodies solid or fluid.*" (*Read the analysis, page* 402.)

As air consists of material particles held far apart from each other by the repulsion of heat among them, we can conceive how an impulse given to a certain portion of the particles is transmitted to those beyond, by the increase of repulsion as they approximate; and from the second layer in the same manner to a third, and so on. And as in fluids the particles all mutually rest against, or repel each other, we can conceive why a motion produced in any part of a mass should be felt in every direction. The explosion of gun-powder, in which there is a sudden formation of a quantity of air, gives a shock all round which spreads as a spherical wave to a great distance.

Although material particles in the form of liquid or solid are so much nearer to each other than in the form of air, we still have many proofs, as stated at page 68, that they are not in absolute contact, and we therefore see the reason why the impulses producing sound should be transmitted through a liquid or solid as through air, and even more quickly and forcibly than in air.

Instances of air carrying sound were given at page 403.—As further examples, we may cite the cases of what are called *sympathetic sounds.* Every elastic body being sonorous, that is to say, being fitted to tremble when struck, with a certain frequency of oscillation depending on its weight and shape, if the air around it be made to tremble by any cause, with the velocity which it is fitted to take on or produce, it immediately begins to tremble in unison; and its motion or sound may continue after the original cause has ceased.—Thus almost any sound produced near a piano-forte whose dampers are raised, finds a responsive string, and bits of paper strewed upon the strings generally, are soon shaken off by those returning unisons or octaves to it, but remain on the others. A harp or guitar in a room with talking company, is often mingling a note with their conversation.—A wine glass or goblet may be made to tremble, and even to fall from a table, by sounding on a violincello near it, the note accordant to its own.

Sounding bodies vibrate much more quickly, or have sharper tones, if placed in light hydrogen; than in common air, and more quickly in common air, than in any of the heavier gases:—because the lighter the air, the less is the resistance to a body moving in it. Thus also a bell will ring under water, but producing a much graver sound than in the air.

That water also is a vehicle of sound, is proved by the fact last mentioned, by the distinctness with which the blows of workers around a diving-bell are heard above, by the fact that fishes hear very acutely, &c.

The following are instances of sound conveyed by solids.—

A scratch of a pin at one end of a log of wood is directly heard by the ear applied at the other end, although through the air it is not at all audible.—Savages often discover the proximity of enemies, or of prey, by applying an ear to the ground and hearing their tread.—The approach of horsemen at night is easily discovered in the same way.—The report of a cannon placed on ice is carried much farther by the ice, than by the air around.—In the military operation of mining, or cutting a way under ground for the purpose of entering, a citadel or blowing up fortifications, the approach of the enemy is often discovered by the subterranean sound of the pioneers' tools.—The awful muttering of earthquakes is merely the sound of subterranean explosions, conveyed from amazing distances, by the solid earth.

The readiness with which solids receive and transmit sound is further perceived in the fact, that a small musical box, while held in the hand, is scarcely audible, but when pressed against a table or a door, will rival a little harp. The vibration communicated from the box pervades the whole of the wood, and the extended surface then acting on the air increases the effect. The construction of violins, harps, guitars, &c., and of sounding-boards generally is governed by the same law. In the dancing-master's *kit* or small fiddle, which he carries in his pocket, there are the same strings and the same bow as for a violin, but it has very little sound, because the extent of its surface is so small. A heavy peace of metal called a *sourdine*, when fixed upon the bridge of a violin, damps the sound, because it is a dead mass resisting the motion of the elastic wood.

It is easy to ascertain whether a kettle boils, by putting one end of a stick or poker on the lid and the other end to the ear: the bubbling of the water appears louder than the rattling of a carriage in the street. A slight blow given to a poker, of which the end is held to the ear, produces a sound which is even painfully strong.

A superstitious man sleeping in the upper story of a lofty house had long heard, during the stillness of night, a singular beating noise, near the head of his bed. There was nothing going on near him or indeed in the whole house to account for it, and he at last deemed it supernatural. Accident however discovered that in a cellar at the bottom and outside of the wall against which his bed stood, there was a wooden clock hanging of which the sound became audible aloft.

The fact of solids conveying sound so much more perfectly than air, has lately been applied to useful purposes in medicine. Dr. Laennec, of Paris, proposed some years ago to listen to what was going on in the interior of the body, but of the chest particularly, by applying one end of a wooden cylinder, which he called a *stethoscope* or *chest inspector*, to the surface, and resting the ear against the other end. The results of this happy thought have been important.

The actions going on in the chest are, the entrance and exit of the air in respiration, the voice, the motion of the blood in the heart and blood-vessels;—and so perfectly do all these declare themselves to a person listening through the *stethoscope*, that an ear once familiar with the natural and healthy sounds, instantly detects certain deviations from them. Hence this instrument becomes a means of ascertaining some diseases in the chest almost as effectual as if there were convenient windows for visual inspection: and when it is considered that a fourth or fifth part of the inhabitants of Europe die of diseases of the chest, such as inflammations, abscesses, consumptions, dropsical collections, aneurisms and various affections of the heart and blood-vessels, each of which requires an appropriate treatment, the importance of such a means may be judged of. By many medical men this instrument was at first ridiculed as quackery and nonsense, and many have yet to learn the use of it. May not both of these facts be attributed to the error which has existed in medical education, of leaving so many practitioners without that knowledge of the general laws of nature, which should enable them to appreciate at once any means likely to be useful in their art, from whatever quarter offered?

" *Velocity of sound.*" (*See the analysis.*)

The velocity of light is such, that for any distance on earth its passage may be regarded as instantaneous. The velocity of sound is considerably less.—If a woodman be observed at his occupation on the hill, his axe is seen to fall some time before the sound of his blow reaches the ear.—The flash of a gun fired at a distance is seen, long before the report is heard.

Most accurate experiments have been made to ascertain the velocity with which sound travels in the atmosphere; and it is found to be 1,142 feet per second, or a mile in about four seconds and a half; varying little either with the density or temperature of the air.

By noting then how long the flash of a gun is seen before the report reaches the ear, we learn the distance of the ship or battery from which the gun is fired. A chasing ship may thus often discover whether she be *nearing* or not the object of her pursuit. In the same manner the distance of thunder may be ascertained: and the reason of the long continued roll of thunder is, that although the lightning darts instantly through a chain of clouds, perhaps of miles in length, the claps or explosions at each interruption of the chain are only heard successively, as the sound arrives at the ear. The pulse at the wrist of a healthy man is a convenient measure of time for ascertaining distances by the motion of sound,—each beat marking nearly a second, and therefore indicating a distance of nearly a quarter of a mile.

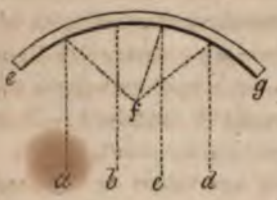
A line of muskets fired at the same instant cannot appear a single report to any person who is not in the centre of a circle, of which the line forms a part.

An extended orchestra of musicians cannot be heard equally well from all situations near them.

Wind affects the velocity of sound, just as a current in water affects the motion of a sailing ship. The effect becomes remarkable in a stormy night, when the wind either brings or resists the coming sound of distant bells.

Sound decreases in intensity from the centre where it originates, according to the same law as light; that is to say, at double distance it is only one-fourth part as strong, &c.

By confining it, however, in tubes, which prevent its spreading, its force diminishes much less rapidly, and it will therefore extend to much greater distances.—In many houses and man-bounds according to the same law as a wave of water, or a ray of light, or an elastic ball, &c. as explained at page 114, *viz.* perpendicularly to the surface, if it fall perpendicularly, but if it fall obliquely on one side, departing with an equal degree of obliquity on the other. To express this very important law shortly, we say that "the angle of reflection is equal to the angle of incidence."—According to this law, any irregular surface must break an echo; and if the irregularity be very considerable, there can be no distinct or audible reflection at all. A regular concave surface, on the contrary, as *e g*, may concentrate sound, and bring all which falls upon it, as from *a b c d*, to the same centre or *focus* as at *f*, so as to produce there a very powerful effect.

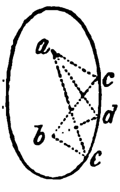


We hence see the reason why echo is much less perfect from the front of a house which has windows and doors than from the plane end, or any plane wall of the same magnitude,—and why the resonance of a room, is so irregular and indistinct when the room contains curtains, carpets, and other furniture, or a crowded assembly. Halls for music have generally plane bare walls. Theatres for the drama, again, have boundaries broken in all ways by rows of boxes, and various ornaments.

The concentration of sound by concave surfaces produces many curious effects both in nature and in art.

There are remarkable situations where the sound from a cascade is concentrated by the surface of a neighbouring cave, so completely that a person accidently bringing his ear into the focus, is astounded, as if the universe were crashing around him. A chair placed in the cave so that a person sitting down in it must bring his ear into the focus, ensures the success of the sometimes amusing experiment.

The centre of a circle is the focus in which sound issuing from it is again collected after reflection: hence the powerful echo near the centre of a round apartment. An *oval* has two



centres or *foci*—one towards each end, as *a* and *b* —and the nature of the curve is such, that sound or light, or heat, issuing around from one of the foci, as *a*, is all directed after reflection at various points, as at *c d e*, &c., to the other focus at *b*. Hence a person uttering a whisper in one focus of an oval room is very audible at the other, although he may not be heard by persons placed between. Such a room may be called a *whispering gallery*. Concave surfaces facing each other, as two alcoves in a garden, or covered recesses on opposite sides of a street or bridge, will enable persons seated in their foci to converse by whispers, notwithstanding louder noises in the space between, and without themselves being overheard in that space.

The reason why a tube conveys sound so far, is, that its sides confine or repress, by a continued reflection, the advancing sound which in the open air would quickly spread laterally and be dissipated. And the reason that the plane surface of a smooth wall, or of water, &c., also conveys sound so far, is, that it similarly prevents the lateral spreading and dissipation, although only on one side.—Persons far apart may converse along a smooth wall.—The clear voice of a street-crier, in a town situated on the border of a lake, may be heard across the water in a calm evening, at a distance of more than five miles—the sound of bells, of course, is audible much farther.—And in the stillness of night, even the splashing oars of a boat will announce its approach to persons waiting at a great distance.

If a sound-reflecting surface be curved inwards, that is, be concave, it not only prevents the spreading of any sound which passes along it, but is constantly condensing the sound by driving the external part inwards. Hence, in a circular space, such as a gallery under a dome, persons close to the wall may whisper to each other at all distances.

An *ear-trumpet* is a tube wide at one end where the sound enters, and narrow at the other where the ear is applied: its sides are so curved, that according to the law of reflection, all the sound which enters is brought to a focus in the narrow end. It thus increases many fold the intensity of a sound which reaches the ear through it, and enables a person who has become deaf to common conversation, to mix again with pleasure in society. The concave hand held behind the ear answers in some degree the purpose of an ear-trumpet, and in a very large theatre is sometimes useful even to persons of quick hearing.—A notorious instance of a sound-collecting surface was the *ear of Dionysius,* in the dungeons of Syracuse. The roof of the prison was so formed as to collect the words, and even whispers of the unhappy prisoners, and to direct them along a hidden conduit to where the tyrant sat listening. The wide spread sail of a ship, rendered concave by a gentle breeze, is also a good collector of sound. It happened once on board a ship sailing along the coast of Brazil, 100 miles from land, that the persons walking on deck, when passing a particular spot, always heard very distinctly the sound of bells, varying as in human rejoicings. All on board came to listen, and were convinced, but the phenomenon was mysterious and inexplicable. Months afterwards it was ascertained, that at the time of observation the bells of the city of St. Salvador, on the Brazilian coast, had been ringing on the occasion of a festival—their sound, therefore, favoured by a gentle wind, had travelled over 100 miles of smooth water, and had been brought to a focus by the sail in the particular situation on the deck where it was listened to. It appears from this that a machine might be constructed having the same relation to sound that a telescope has to light.

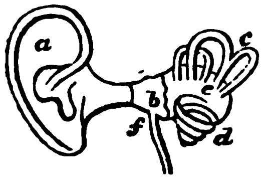
The *speaking trumpet* is made according to the same law of reflected sound, with the view of directing the strength of the voice to a particular point. The sea captain uses it to send his orders aloft, where the unaided voice would be lost in the noise of the wind and waves—or to hail ships at a distance. A similar form of mouth is used for the *bugle horn* and common trumpet, and fits them to sound the note of command amid the uproar of contending armies.

Some amusing effects have been produced by operating on sounds with tubes and concave surfaces. What was termed the *invisible girl,* was a contrivance where the questions of visiters were caught by a concealed concave, and carried to the director who sat at a distance; and his replies, as in the whispering gallery, became audible to the inquirers alone.

The concave, undulating, and perfectly polished surface of many sea-shells, fits them to catch, to concentrate, and to return the pulses of all sounds that happen to be trembling about them, so as to produce that curious resonance from within, which closely resembles the sound of the distant ocean—so closely, that the spirited boy, after studying the interesting stories of voyagers which paint dangers to be nobly braved, and charms of nature to be seen in distant lands, often feeds his imagination with this voice of the shell, and fancies himself already riding among the billows.

The animal ear,

so admirably adapted to perceive the evanescent trembling of the air, has of course a structure in strict relation to their nature as now explained. The parts of the ear, and the progress of sound to the sentient nerve, may be simply described as follows:



1st. There is externally a wide-mouthed tube or ear trumpet *a*, for catching and concentrating the waves of sound. It is moveable in many animals, so that they can direct it to the place from which the sound comes.

2d. The sound concentrated at the bottom of the ear-tube, falls upon a membrane stretched like the top of an ordinary drum, over the *tympanum* or *drum of the ear b*, and causes it to vibrate. That its motion may be free, the air contained within the drum has free communication with the external air, by the open passage *f*, called the *Eustachian tube*, leading to the back of the mouth. A degree of deafness ensues when this tube is obstructed, as by wax; and a crack or sudden noise, with immediate return of acute hearing, is generally experienced when, in the effort of sneezing or otherwise, the obstruction is removed.

3d. The vibrations of the membrane of the drum are conveyed farther inwards by a chain of four bones (not here represened on account of their minuteness,) reaching from its centre to the *oval door* or *window* of the labyrinth *e*.

4th. The labyrinth, or complex inner compartment of the ear, over which the nerve of hearing is spread as a lining, is full of water; and therefore, by the law of fluid pressure (*see page* 238,) when the force of the moving membrane of the drum acting through the chain of bones, is made to compress the water, the pressure is felt instantly over the whole cavity, as in a hydrostatic press.—The labyrinth consists of the *vestibule* e, the three *semicircular canals* c, imbedded in the hard bone, and a winding cavity, called the *cochlea* d, like that of a snail-shell, in which fibres, stretched across like harp-strings, constitute the *lyra*.—The exact uses of these various parts are not yet perfectly known. The membrane of the tympanum may be pierced, and the chain of bones may be broken without loss of hearing. Considerable diversity of form and dimension is found in different animals. The bone containing the cavities of the ear is the hardest in the body, and is the first formed.

The ear has the power of judging of the direction in which sound comes. This is strikingly exemplified in the fact that, when horses or mules march in company at night, those in front direct their ears forwards; those in the rear, turn them backwards; and those in the centre, turn them laterally or across;—the whole troop seeming to be actuated by one feeling, which watches the common safety.

The intensity of sound is to the ear a measure of distance.—In a windy night the sound of a distant bell may be brought so quickly, that it has not yet had time to spread and be weakened; and a person is often roused from a reverie by its unusual loudness and apparent nearness. When a stormy wind blows directly upon a coast, and rolls the great waves in upon the sandy beach, or among the rocks, the countryman living far inland hears the uproar, as if the ocean had burst its boundaries, and were pouring in upon the land.—The scene-contrivers at our theatres heighten the illusion of an approaching procession, by letting the accompanying music be first heard from a closed chamber or in a feeble tone, and afterwards by making it gradually louder and louder. To the imagination perhaps already excited to the highest pitch, by the drama of some divine mind, the advancing host is thus more vividly pourtrayed, than it could be by any other expedient; and when at last with the thunder of drums and trumpets from the front of the stage, the troop also appears, the effect is complete.—It is the varying loudness of the music of the Æolian harp which produces the feeling that the heavenly choir is sometimes approaching and sometimes receding.

PART III.

SECTION V.

DOCTRINES OF FLUIDITY IN RELATION TO ANIMALS.

In the preceding sections, occasional illustrations of the laws of fluidity have been taken from the animal economy: but there are many other particulars of the same class, and of great interest, which it is convenient to consider apart under the four heads of, 1st. *The circulation of the blood;* 2d. *The respiration and voice;* 3d. *The digestion;* and 4th. *The pelvic phenomena.* It is important to remark here, that this section cannot be understood by a person ignorant of those which precede.

THE CIRCULATION OF THE BLOOD.

Perhaps there are few points more remarkable in the history of the progress by which man has arrived at his present knowledge of the universe, than that it is only two hundred years since he discovered that the blood in his own and in other animal bodies is constantly circulating. England claims as one of her sons, the man whose powerful intellect at last established this truth, in opposition to strong appearances, and to the most fixed prejudices. Dr. Harvey published his proofs in the year 1619. A person who tries to imagine what the science of medicine could have been while it took no account of this fact, on which, as a basis, all certain reasoning about the phenomena of life must rest, is prepared for what old medical books exhibit of the writhings of human reason, in attempts to explain and to form theories, while a fatal error was mixed with every supposition.—The chief circumstance which prevented the earlier discovery of the circulation was, that on examining dead bodies, the arteries were always found empty of blood;—which was the reason, also, of these vessels being called *arteries*, or *air tubes*.

We now know, that as the Thames water spreads over London in pipes, to supply the inhabitants generally, and to answer the particular purposes of brewers, bakers, tanners, and others, and is then in great part returned to where the current sweeps away the impurities; so, nearly, in the human body, does the blood spread from the centre, through the arteries, to nourish all the parts, and to supply material of secretion to the liver, the kidneys, the stomach, and other viscera; and returns from these by the veins, towards the heart and lungs, to be purified, and to have its waste replenished, that it may again renew its course.

The circulation may be more particularly described thus. From the left chamber or *ventricle* of the strong muscular mass the *heart*, a large tube arises, called the *aorta;* and by a continued division or ramification, opens a way for the bright scarlet blood to every the minutest part of the living frame,—the extreme divisions or twigs being so small, that they are called *capillary* or hair-like tubes. At the terminations of these vessels, the blood after answering the purposes of general nutrition, &c., by which it loses its bright colour, enters the commencements of the *venous tree* or returning channel; and gliding successively from smaller to larger branches, returns towards the right chamber or ventricle of the heart, requiring purification and partial renewal. Considering the great arterial and venous systems of the body as *twin trees*—the *scarlet* and the *purple*, with corresponding and meeting branches, and with trunks will touch each other at the heart, it will appear that they again completely meet or inosculate by their extreme roots, and thus form a continued or circular channel. The root of the venous tree by which the blood spreads from the right chamber of the heart to the lungs, is called the *pulmonary artery*, and that of the arterial tree, by which the blood returns to the left chamber, is called the pulmonary vein. Both of these ramify in the spungy masses of the lungs, forming a great part of the pulmonary substance. Fresh material for the blood is brought from the *digestive organs* by the *lacteal absorbents* and *thoracic duct*, and is constantly pouring into a large vein near the heart, to be completely mixed with the dark or returning blood by a violent agitation or *churning* during its passage through the heart. The mixture on leaving the right ventricle is strained through the minute ramifications of the vessels in the lungs, and at the same time is exposed to the action of the air entering the cells of the lungs in respiration, by which exposure the dark purple blood becomes again pure scarlet, and when it reaches the left chamber or ventricle, is ready to set out on its journey as before, charged with new life and nourishment. The two chambers or ventricles of the heart have each an anti-chamber or *auricle* (so called from an external resemblance to a dog's ear,) into which the blood is first received from the veins; and there are valvular doors between the auricle and ventricle, which allow the blood to pass readily into the ventricle, but oppose its recoil during the ventricular contraction. Similarly acting valves are placed between the ventricles and great arteries. There are valves also in many of the veins, over the body, to secure the natuaral course of the circulation. Besides the important change or purification which the blood undergoes in passing through the lungs, its composition is much influenced by the action of the kidneys, of the exhalants of the skin, and of the liver,—the two former relieving it from superfluous moisture and salts, the last, from a large quantity of matter in the form of bile.

The description given above of the circulation of the blood is only an outline; and yet by showing the manner in which fresh material enters, it contains more than Harvey knew of the subject. In this department of knowledge, as in most others, we have advanced from the very general and vague, to the more particular and precise:—and just as the general nature of steam was known long before it served in steam-engines: and as the period of the moon's revolution had been accurately observed for thousands of years before the fluctuations in her velocity could be calculated so as to make her the mariner's best guide in his courses across the ocean,—so, when Harvey had proved the simple fact of the circulation of the blood, he had left much yet to be done, by observing and reasoning from minutiæ, to render the knowledge available for the many useful purposes which it is calculated to serve. Within a few years only, has the importance of the subordinate circumstances been fully appreciated,—as is evinced by the numerous works composed to elucidate them; but many of which works have served only to prove, that if the difficulties were to be solved by natural philosophy, medical men in general had not yet studied it sufficiently to be able to use it successfully. In this section it will be attempted to place certain important points of the subject in a clear light; and by referring directly to the general laws of nature, as explained in the body of the work, to settle existing disputes on some of these points, to remove remaining doubts on others, and to suggest some important new applications.

The fact of the circulation of the blood being once admitted, an inquirer who contemplates the apparatus by which it is effected, is led by the general analogies of nature to conceive—. 1st. That the ventricle of the heart, at each contraction, empties itself into the great artery;—2d. That the consequent jet causes a wave to pass along to the extremities of the arterial tree, accounted simply elastic, so as to produce every where what is called the pulse;—3d. That the force of the heart, acting along the arteries, forces the blood through their open capillary extremities into the commencing veins and along the veins back to the heart again. Now these guesses, which Harvey believed completely to describe the circulation, are all nearly true: but the following facts, and others ascertained since Harvey's day, not exactly squaring with them, have rendered farther investigation necessary.—1st. The pulse, instead of being a *distinctly progressive* wave, is almost as instantaneous over the whole body as a shock of electricity;—2d. The arteries are all found empty after death; and if an artery be tied in the living body, the part beyond the ligature, although the action of the heart cannot reach it, is soon emptied through the capillaries into the veins;—3d. Although the rapidity of of the blood's passage through the capillaries varies very much, it does not vary in exact accordance with the changes in the rapidity or force of the heart's action. In analysing this subject, it is convenient to follow the blood round from the heart to the heart again, through the three stages of, 1st. *The arteries;* 2d. *The capillaries;* 3d. *The veins.*

Motion of the blood in the arteries.

The contractions of the heart inject the blood into the arteries with a force maintaining such a tension in them, that according to the interesting experiments of Dr. Hales, recorded in his *Statical Essays*, if any artery of a large animal like a horse, be made to communicate with an upright tube, the blood will ascend in the tube to a height of about ten feet above the level of the heart, and will there continue, rising and falling a few inches with each pulsation of the heart. Now a column of *ten* feet, as explained at page 241, indicates a pressure of about *four and a half* pounds on a square inch of surface: this, therefore, is the force of the heart urging the blood along the arteries into the veins. The opposing tension of the veins is much less, because, as will be explained under the proper head, the blood readily escapes from them into the heart: Hales found that in a tube communicating with a vein, the blood stood only a few inches higher than the level of the heart. In small animals he ascertained the tension of artery and vein to be less than in large ones; and the ratios deduced for the human body, under ordinary circumstances, were eight feet column, or nearly four pounds per inch for the arteries: and half a foot column, or a quarter of a pound per inch for the veins.

Arteries examined after death are found to consist of, 1st. an outer coat of strong *elastic substance;* 2d. a middle coat of *circular fibres;* and 3d. an inner coat of *smooth lining membrane.* Their elasticity or power of resisting change of dimension, and of returning to a middle state from either dilatation or compression, because remaining in the dead artery, was the most obvious property, and was that first attended to. Minute observation of the phenomena of life has since determined the following facts, proving and illustrating a contractility resident in the fibrous coat.

1. A small living artery, cut across, soon contracts so as to close its canal, and arrest hemorrhage.

2. While an animal is bleeding to death, the arteries accommodating themselves to the decreasing quantity of blood, contract far beyond the degree to which their simple elasticity would carry them; and they relax again after death. Dr. Hales took seventeen quarts of blood from a horse before it died, in whose body only three quarts more were found altogether, and yet the moment before death the tension of the arteries sustained a column of two feet of blood in his experimental tube.

3. The artery of a living animal, if exposed by dissection to the air, sometimes will contract in a few minutes to a great degree: and in such a case, only a single fibre of the artery may be effected, narrowing the channel like a thread tied round it. (*See Parry on the pulse.*)

4. When a living artery is tied, the part between the ligature and the nearest branch on the side of the heart gradually contracts, and becomes at last a solid or impervious cord.

Fluctuation in the vital action of parts, is often attended with sudden increase or diminution of caliber in the arteries concerned.

Although these facts prove indubitably a contractility in the coats of arteries distinct from their elasticity, still, because the circular fibres do not resemble common muscles in colour or in chemical composition, or in being immediately obedient to the stimuli of electricity, pricking, great heat, &c., their contractility was by many persons for a long time denied. The dispute, however, was often more about the words *contractility* and *muscularity*, than about facts.

The pulse in the arteries, chiefly as regards its almost instantaneous occurrence over the whole system, in all states of arterial dilatation, and its great strength and sharpness in very small and remote branches, points also to the active contractility of the aterial coats: for,

1. Were the arterial tree in the living body a system of tubes

as readily admitting of farther dilatation as in the dead body, the first part or trunk would effect the motion of the blood beyond it, nearly as the *air-vessel* (see page 291) placed at the commencement of artificial arrangements of water-pipes affects the motion of the water in them;—that is to say, as this converts the sudden and interrupted jets of water from pumps of *fire-engines, town-supplying pipes,* &c. into a uniform stream with scarcely a remnant of shock, so, in the arterial branches, the simple elasticity would cause a more tranquil flow and a quieter beat than that bounding pulse of life felt in the remote artery of the wrist, as sensibly, in proportion, as near the heart itself.

2. Were the pulse a wave advancing in tubes that yielded as readily as the dead arteries in their middle states of dilatation, it would be very distinctly progressive from the heart to the extremities; but it is felt so instantly over the whole body, as to be compared commonly to a shock of electricity.

3. A pulse may be produced artificially in the arteries of a body recently dead, by filling them with water to the tension of life, and then injecting at intervals, by a syringe, as much water as the heart throws of blood at a pulse: but although the artery is then distended nearly to the limit of its dilatability, and is therefore rendered rigid, the beats are very different from those of the living pulse. A similar experiment, tried by connecting the artery of a dead animal with the corresponding artery of a living one, has a similar result.

4. A tube, extensively elastic, that it might convey a wave of liquid with a velocity approaching to that of the pulse, would require to be so tense, from fulness, as to be discernible always by the touch, through any imbedding medium such as flesh, like a hard cylinder or cord; and it would be acting constantly as a spring tending to straighten itself, and therefore would be stiffening the parts through which it passed. Now the living arteries, between their pulsations, are almost as soft and compressible as the surrounding flesh, and offer no perceivable opposition to bending, in any movement of the parts. This may be verified by examination of the lips, for instance, or of the fingers; but when a person sits cross-legged, the well-

known shaking of the suspended foot, in unison with the pulse, shows the recurring efforts of the artery to straighten itself, during the moments of greater tension.

5. A bulky wave in elastic vessels would have to recoil from the extremities, or to pass through them as a gush: and the recoil would be particularly observable near the ligature of a tied artery: but examination has not detected such effects in the living body. The tying of an artery *beyond* an aneurismal tumour, if it checked a strong wave, would almost certainly produce bursting; yet Mr. Wardrope and others have lately performed this operation with successful issue.

6. The wave would be more interrupted by the bandage in the operation of bleeding, than the living pulse is.

7. The pulse of a paralytic limb often seems more affected than mere change of size in the artery will account for. The same is true, in an opposite way, of the pulse in an artery leading to an inflamed part.

8. If the abdomen of a living animal be opened, the mesenteric artery, in all its ramifications, is seen stiffened and raised up suddenly with every pulsation, in a manner which the spreading of newly received blood in a very yielding vessel ill accounts for.

9. In the interesting experiments of *Bichât*, *Parry*, and others, to ascertain the exact extent of the supposed dilatation and contraction of arteries during a pulse, not the slightest degree of either was discernible, even when sought for with microscopes.

To explain these and other phenomena, then, it seems necessary to admit, as occurring throughout the whole body, and almost simultaneously with the contraction of the heart itself, such an action of the contractile fibres of the arteries, as to modify their natural elasticity, and to render them rigid enough, in all degrees of dilatation, for the heart to produce its effects through them almost as it would through tubes of metal. Dr. Young, in a paper published in the Philosophical Transactions for 1809, and characterized by the usual elegance and precision of his writings, has adduced experiments and calculations, to show that waves in elastic vessels advance more quickly than was before imagined; but the spreading of the pulse seems to be yet more rapid than his calculation anticipates.—It is evident, that when arteries, in consequence of depletion, are contracted beyond the middle station of their elasticity, their tension and power of quickly conveying the pulse must be dependent altogether on the condition of their contractile fibres.

The careful experiments which could detect no change of size in the arteries during the pulse, while they disprove the ancient belief of a considerable tumefaction or wave passing along, or of a considerable filling and emptying of arteries, like what occurs in the heart, might also be supposed positively to disprove the occurence of any general constriction of the vessels on their contents—but erroneously: for if a man's arterial system, considered as one cavity, be supposed to contain five pounds of blood (which is probably near the truth,) and if the vessels be thought to embrace their contents, even between the pulses, with force enough to have all a rounded or cylindrical form, although remaining soft and yielding to the pressure of the finger, and if we suppose their coats during the pulse, to be thrown into a sudden contraction, as if in obedience to an electrical shock, still, because blood is incompressible, and because just as much enters the arteries with every pulse as escapes from them before the next, their bulk would not sensibly diminish by the strongest conceivable action of their coats; of which action the only sensible effects would be, that the soft, yielding, and, in some places, compressed tubes would be suddenly converted into hard or resisting cylinders; and that wherever, by any accidental pressure, an artery had been flattened, in regaining its cylindrical form it would strike or pulsate against the compressing body.—Whether such an action as this contributes to produce the arterial pulse will be considered under the head of "*the pulse*," after we have seen how the blood moves in the capillaries and veins.

In any admissible view, however, of arterial action, we find that the arteries contribute to the motion of the blood, only as tubes which convey it; their tension, and therefore, the force with which the blood is pressed into the capillaries, being derived from the heart alone. Many physiologists have had a confused belief that the arteries aided actively in propelling the blood; but a very little reflection would have shown that as they have no vermicular or progressive contraction, like the intestines, they can no more *propel* the fluid within them, than any other rigid or elastic tubes.—Although they are thus in no degree instrumental in the propulsion of the blood, still by more permanently enlarging or diminishing their caliber, that is, by merely becoming larger or smaller conduits, they may much influence its distribution, and the speed of its transmission.[*]

The nature of this work does not allow us to record here historically the various errors into which even able men have fallen, in attempting to explain the office of the arteries, but we shall glance at the following.—*Dr. Monroe* and *John Hunter*, two of the most able physiologists that the world has seen, believed that the arteries did almost as much in propelling the blood as the heart itself; and some teachers of the present day also speak of their *propulsive action*. We need not repeat the refutation of this opinion. The ingenious Bichât, unable to detect either momentary contraction or dilatation in the arteries, thought that the blood was pushed along them by the heart, instantly through their whole extent, as a solid rod of metal or wood is advanced by an impulse at one end. Dr. Parry took nearly the same view of the subject, and illustrated his idea by referring to the experiment of moving a whole line of billiard-balls by striking the extreme one. Both these authors erred by neglecting the hydrostatical truth, that pressure in a fluid operates equally in all directions, and therefore, that fluid pressed into a tube, tends to dilate the tube, just as powerfully as to drive the fluid forward: and they did not advert to the fact that the stream of blood in the small arteries is nearly uniform. The blood could only advance, as they supposed, by the arteries becoming, for an instant, absolutely rigid, through an action of their contractile fibres.

---

[*] How it can be said, that the arteries contribute to the motion of the blood, only as rigid or elastic tubes which convey it, while it is admitted that they possess the power of enlarging and diminishing their caliber, and thus influencing its distribution and the speed of its transmission, we know not. They must, by their expansive and contractile power exercise an influence on the circulation of the blood.
Am. Ed.

It merits notice here, although not strictly a mechanical fact, that arteries permanently increase or diminish in size when a permanent change takes place in the demand for their service. The arteries of the *gravid uterus*, or of an increasing tumour, grow with the part supplied, while on the contrary, those of a stump left after amputation, soon remarkably diminish. If the chief artery of a limb be obliterated by any cause, as after the operation for aneurism, the small collateral anastomosing branches increase in size to do its duty.

It is further remarkable, that when arteries are called upon to carry an increased quantity of blood, they often become tortuous or serpentine, as well as larger; and that arteries leading to parts whose actions are naturally intermitting or fluctuating, have generally the tortuous form. Of these truths, the arteries leading to rapidly growing tumours, or to varicose aneurisms, and the arteries of the uterus and testes, may serve as instances. This bending of arteries, and the very curious division into many branches which again reunite, found in those leading to the brains of some animals, do not seem intended to slacken the rapidity of the sanguineous current, but to give the artery a greater control over the supply.

Passage of the blood through the capillaries.

We have seen that the heart keeps up a tension or pressure in the arteries, of about four pounds on the square inch of their surface; and with this force, therefore, is propelling the blood into the capillaries. If these last were passive tubes, constantly open, such force would be sufficient to press the blood through them with a certain uniform velocity: but they are vessels of great and varying activity: it is among them that the nutrition of the different textures of the body takes place, as of *muscle*, *bone*, *membrane*, &c., and that all the secretions from the blood are performed, as of *bile*, *gastric juice* or *saliva*, and to perform such varied and often fluctuating offices, they require to be able to control, in all ways, the motion of the blood passing through them. The capillaries of the cheek, under the influence of shame, dilate instantly, and admit more blood, producing what is called a *blush*;—under the influence of anger or fear, they suddenly empty themselves, and the countenance becomes pallid—tears or saliva gush in a moment, and in a moment are again dried up—if a person having inflammation in one hand be blooded from corresponding veins in both arms at the same time, twice or thrice as much blood will flow from the diseased side as from the other. Similar changes occur in many other instances. Now the only mechanical action of vessels, capable of causing these phenomena, must occur in contractile or muscular coats; and with reference to such action it merits notice that arterial branches have always more of the fibrous or contractile coat in proportion as they are smaller.

A muscular capillary tube strong enough to shut itself against the arterial current from the heart is also strong enough to propel the blood to the heart again through the veins, even if the resistance on that side were as great as the force on the other. For if we suppose the first circular fibre of the tube to close itself completely, it would, of course, be exerting the same repellent force on both sides, or as regarded both the artery and vein. If then the series of ring fibres forming the tube were to contract in succession towards the vein, as the fibres of the intestinal canal contract in propelling the food, it is evident that all the blood in the capillary would thereby be pressed into the vein towards the heart. If after this the capillary relaxed on the side of the artery, so as to admit more blood, and again contracted towards the vein as before, it might produce a forward motion of the blood in the vein, independently of the heart. We, of course, state this merely as a possibility, for the intimate nature of capillary action is not visible, and has not been positively ascertained.

It is capillary action which absorbs and moves the fluids of the classes of animals which have no heart. It must also be the power which moves the blood in warm-blooded monsters formed without hearts. There are cases of apparent death among human beings where the heart remains inactive for days, and yet a degree of circulation sufficient to preserve life is carried on by the capillaries. In illustration of capillary action, we have also the absorption, by the lacteals, of nutriment from the alimentary canal; and perhaps, to a certain extent, the circulation of the blood in the livers of animals. In this last case, the blood collected by veins from the abdominal viscera, instead of going directly to the heart, is again distributed through the liver by the branches of the *vena portæ*, and is then again collected by ordinary veins, and carried to the heart: it thus moves through two sets of capillaries in passing from the arteries to the heart again.

The action of the capillaries, is the cause of that singular phenomenon which prevented the ancients from discovering the circulation of the blood, *viz.* the empty state of the arteries after death. All the muscular parts of an animal, including, therefore, the contractile coats of vessels, retain their life, or power of contracting, for a considerable time after respiration has ceased,—as is seen in the recovery of persons apparently drowned or suffocated; in the leaping of a heart taken from an animal just killed; in the actions resembling life which can be produced, by the agency of galvanism, in a body recently dead: but the fact is seen still more aptly for our purpose, in the total disappearance of a local inflammation after the death of the patient,—for inflammation involves a gorging or over-distension of the capillaries, into which when the heart has ceased to press blood, the contractile force remaining in them, even under disease and in a dead animal, is sufficient to squeeze the blood out of them, and often to remove all trace of the malady which has killed.—In ordinary cases, then, the capillaries throughout the body remain alive and active for a considerable time after breathing has ceased, working like innumerable little pumps, and emptying the arteries into the veins. As the red blood is their proper sustenance as well as stimulus, they work as long as there is any of it coming from the arteries behind them; except however, the capillaries of the lungs, which soon cease to act, because, after breathing has ceased, they are filled with black blood, and are moreover compressed by the collapse of the chest; and all the blood accumulates behind them. The capillaries may continue to be filled from the arteries, either in consequence of their elasticity opening them with what is called a suction power, or of an absorbent power dependent on life, like that of the lacteals, and of the absorbents all over the body, and perhaps, of the vessels in the roots of vegetables. When death is produced by lightning, or by the poisons which destroy all muscular irritability, the arteries after death are found to contain blood like the veins. In a living body, if an artery be tied, the part beyond the ligature is soon emptied into the veins, and becomes flat.—The experiment has been made even upon the aorta itself.

The empty state of the arteries after death is still ascribed, by some teachers, to the momentum with which the blood is supposed to be thrown out from the heart in its last contraction, sufficient, say they, to squirt it fairly through the most distant capillaries: a doctrine exemplifying the carelessness with which able men sometimes receive and repeat opinions, to which their attention has never been fully awakened. Such an effect would not follow, even if the action of a dying heart were the strongest possible; while, in reality, it is in most cases so feeble, that the pulse for some time ceases to be perceptible at the extremities, and the diminished circulation lets them become cold.—Other physiologists teach that an artery is capable of contracting directly upon its contents, so as to expel even the last drop;—but large arteries, when emptying, do not contract *roundly* like an intestine: they become *flat* like elastic tubes of leather *sucked* empty, and no contractile action of the vessel itself could bring its sides together in such a manner. If arteries emptied themselves by their own action, the pulmonary artery should be more certainly empty than the aorta, because it is shorter: yet it is always full; chiefly for the reason already stated, that the pulmonary capillaries cease to act after respiration has ceased, on account of the blood in them being the venous or dark blood, and therefore not stimulant.

Passage of blood through the veins.

The veins have much thinner coats than the arteries; and if taken altogether, have much greater capacity, because they exist, in many situations, as double sets—an exterior and an interior; they have also very frequent inosculations or communications with each other throughout their whole course.

The simple weight of the column of blood in any descending artery is just sufficient to raise the blood through open capillaries to an equal height in the corresponding vein, according to the hydrostatical law, that fluids attain the same level in all communicating vessels; and therefore as the arch of the aorta rises considerably above the heart, the pressure of the descending arterial column of blood would be sufficient to lift that in the veins not only up to the heart, but considerably beyond it. In addition to this influence of gravity on the venous current, the blood is pressed into the arteries, and from them therefore towards the veins, with a force from the heart itself, as stated above, of about four pounds to the square inch, or, in other words, as if there were a column of blood eight feet higher than the heart urging the current. It might be expected from the law of equal diffusion of pressure in fluids, that these causes would soon produce a tension in the veins as great as in the arteries. This does not happen, however, because the blood has a ready escape from the veins through the right ventricle of the heart. Under ordinary circumstances, there can be no greater tension in the veins than just enough to lift the blood to the heart and to overcome the friction; just as in an upright leathern tube, open at top, and receiving water from a powerful forcing pump through a small opening at its bottom, there never can be greater tension or pressure than what corresponds to the height of fluid column in the tube, and to the friction between the fluid and tube. In Dr. Hales' experiments, already alluded to, a tube connected with a vein so as to receive its blood, became filled with blood to a height only of about six inches above the level of the heart.

As Dr. H. generally cut the vein completely across, and inserted the tube into the portion leading from the capillaries, he would have discovered the whole power with which the blood is pushed along the veins from the capillaries, but for the free lateral communication of veins with each other, which reduces the tension even in an obstructed branch, to the degree existing in the system generally. When from agitation of the animal, or any straining exertion, the passage of the blood into the heart was impeded, all the veins became tense, and a tube inserted into the returning jugular had blood running over, at a height of three feet above the heart.

If the blood did not escape from the veins, as above described, the only cause which could prevent the venous tension from becoming as great as the arterial, would be obstruction in the capillaries: but the following facts and considerations prove that these vessels, which in the dead body allow the passage of injections, in the living body freely allow the passage of blood. 1st. Magendie laid bare the chief artery and vein of a living limb, and detached them at the part, from the flesh underneath, so that he could apply a tight bandage round the limb without including them, and could thus render them the only channels of circulation for the lower limb. He then found, that when a separate ligature was put upon the vein, to prevent the return of its blood to the heart, and a puncture was made beyond the ligature, the flux of blood from the puncture was rapid or slow, according as the heart was allowed to produce a greater or less degree of tension in the artery:—this tension was regulated by compressing the artery between the fingers. 2d. After a similar preparation of the parts, the blood will ascend in a tube from the obstructed vein very nearly as high as from the artery. 3d. In the common operation of bleeding, when the vein is first punctured the blood often jets from it as from an artery, staining the top of a lofty bedstead. 4th. The microscope discovers, in the capillaries, a uniform forward motion of the blood, as if it were obeying the steady pressure of the arterial tension, and not any intermitting action. 5th. Disturbed action of the heart, by obstructing the passage of the blood through it, is very soon attended with a tumefaction of all the veins leading to the heart: the tumefaction becomes very visible about the neck and head, and in the liver produces swelling and acute pain. 6th. Dr. Young, from experiments made by him, and reported in the Philosophical Transactions for 1809, concluded, that perfectly open capillaries, of the size existing in the living body, should just retard a flow of blood urged by the usual arterial tension, in the degree which really occurs:—a correspondence proving that they must be open; and soon vessels, however small, and how slowly soever they transmit the blood, still, if the escape of blood from the veins were arrested, would transmit the arterial tension without diminution. 7th. The action of the capillaries, which after death empties the arteries into the veins, proves that, under certain circumstances, the venous tension may become even greater than the arterial.—These facts, then, and others that might be mentioned, prove incontestably that the blood is pressed into the veins from the arteries and capillaries, with force sufficient to lift it, not only to the heart again, but many feet farther, *viz.* about as far as it would ascend in a tube rising from the tense arteries themselves. So little, however, has this important truth been understood, that in elementary works of authority lately published, the venous current is treated of as a very obscure subject; and some authors, in their anxiety to explain it, have assigned causes for it, which, as will appear hereafter, are positive absurdities in physics. The difficulty in the question seems to have arisen from the great disparity observed between the tension in the arteries and in the veins, while the reflection did not occur that it was owing to there being a free passage or outlet from the veins through the heart.

The ingenious Bichât, with a carelessness of facts extraordinary in him, persuaded himself that the influence of the heart ceased entirely at the capillaries, and that the blood was returned through the veins by the action of the capillaries alone. How could he avoid the single reflection, that, if the purpose of the arteries had been merely to convey the blood to the capillaries, and not to bear the force which pressed it *through* them, the extraordinary strength of the arterial coats, and the great power of the heart to fill them, and keep up the tension described, would have been quite superfluous?—and he knew that nature does nothing in vain.* The preceding remark applies strikingly to the pulmonary artery, of which no branch exceeds a few inches in length.

The uniform current of blood along the veins, produced, as now explained, by the combined influence of the heart and capillaries, and which becomes apparent in the operation of bleeding, suffers a considerable disturbence in the neighbourhood of the heart from three causes. 1st. As there is no valve between the veins and the auricles of the heart, each contraction of the right auricle tends to throw the blood back into the veins, as well as forward into the ventricle; it thus produces the venous pulse often felt in the neighbourhood of the chest. 2d. When the chest is expanded by inspiration, it is more roomy than during the collapse of expiration, and the blood then enters it more readily. 3d. While the chest is *inhaling* or *drawing in* air, that is to say, expanding so as to diminish the tension or pressure of the air within it (see *Pneumatics,*) it is by the same action favouring the entrance of blood through the veins towards the heart placed in it;—on the contrary, while it is *exhaling* or *throwing out* air, it is, with equal force, resisting the entrance of blood, and slackening, or even causing recoil of the inward current. This favouring or resisting force, as will be hereafter shown, is only such as to lift or support a column of blood of about half an inch in height.—It appears then that the entrance of blood into the chest fluctuates by reason of the respiration, as the entrance of a river stream into the sea fluctuates by reason of the ebbing and flowing of the tide. An eye watching the jugular vein, under favourable circumstances, may see it tense or slack in accordance with the opening and shutting of the chest.

---

* This is a fashionable but very incorrect mode of reasoning, the influence of the heart *may* cease with the capillaries, and yet nature have done nothing in vain; before such a charge could be made against nature we must possess an infinitely more precise knowledge of the circulatory forces, and the functions of the arterial system. AM. ED.

It still remains to be ascertained whether or not veins have n themselves any active contractile power, such as can partialy empty a lower portion into a higher beyond an adjoining valve. If so, the valve, by then bearing the pressure, would let more blood be easily raised from below into the portion so relieved: and the action, without being equal to the office of completely emptying any portion of a vein, would still have the effect of dividing a long heavy column into a number of short columns of comparatively little resistance. It is certain at least, that the valves in the veins, by preventing the falling back of blood which has once passed towards the heart, must affect its flow during bodily exercise; for every time that pressure is made on a vein by a swelling muscle or otherwise, the blood in the part must be forced forward, and cannot return.

The veins which are surrounded by muscles are thinner and weaker than those supported only by the skin. The external veins of the legs are almost as strong as arteries. Proving, however, that the fabric of veins is much weaker than that of arteries, we may mention the fact that any vein in the living body made to communicate directly with an artery, soon exhibits what is called a *varicose aneurism*, and swells to bursting. Veins possess power, to a great extent, of adapting themselves to the varying quantity of blood.

Some recent authors, as stated above, either not aware of the facts, which prove that the blood is every where pressed into the veins, with force much more than sufficient to raise it to the heart again; or being unable, from their little familiarity with physics, to draw exact conclusions from the facts, or to avoid errors in their own hypotheses, have promulgated the opinion that the progression of the blood in the veins is greatly owing to a partial vacuum or a suction power in the heart or chest; that is to say, to the atmospheric pressure remaining constant on the body generally, while it is occasionally lessened about the heart:—now the whole influence of this effect or circumstance, as stated above, is merely a slight disturbance of the uniformity of the venous current near the chest. Such a doctrine could not be proposed or entertained for a moment by a person understanding the principle of a common household pump; and that it has been published and tolerated by certain professional men in the present time, will remain a proof to posterity of the deficiency, as regards fundamental science or natural philosophy, now existing in the ordinary medical education. Much ingenuity has been wasted upon it, particulary by Drs. Carson and Barry, the latter of whom, after making laborious experimental investigations on living animals, has even attempted to build upon it a superstructure of medical theory and practice! To say that the influence of the heart or chest is the power which draws the blood to the heart from the general system, is exactly as if one asserted that the rising and falling of the tide at the mouth of a river is the power which collects the tributary streams in the interior country.

We shall enter into a little detail on this subject, because the discussion will elucidate some minor points connected with the circulation.

Presuming, then, that the reader perfectly understands the theory of pumps, and therefore of atmospheric pressure, as explained under *pneumatics*, he will readily understand the two following propositions, either of which proves it to be a physical impossibility, that a sucking action of the heart or chest can be a cause of the blood's motion along the veins. 1st. The veins are pliant tubes free to collapse, and no pump can lift liquid through such. 2d. The *suction power* of the chest in healthy respiration is too weak to lift liquid even one inch through tubes of any kind.

A practical illustration of the first proposition is afforded by putting the point of a syringe into a piece of gut, or eel-skin, or vein filled with water, and then trying to pump up the water. The result will be, that the fluid close to the mouth of the syringe will enter it, and then the sides of the pliant tube will collapse as a valve against the syringe, making an end of the experiment. In exact proportion to the rigidity of the tube will be the distance to which the influence of the syringe will extend in it: if, for instance, half an ounce of pressure on the square inch of its surface be required to make it collapse, then the pump will draw up one inch of water, and so for other proportions. If during the action of the syringe, the tube were allowed to open at the bottom into a vessel of water, instead of the syringe then drawing any more water from the vessel into the tube, the original contents of the tube would straightway be discharged downwards into the vessel;- the result being the same even if there were a thousand tributary streams pouring into the tube, unless they entered with force enough to rise up to the syringe.

The explanation of all these facts is found in the pressure of the atmosphere (see from page 299 to page 386,) seeking entrance every where at the surface of the earth, with a force of fifteen pounds per square inch, and overcoming any opposing force less than this;—a pressure which is sufficient, therefore, to push a column of water of thirty-four feet in height, through a rigid tube into the vacuum of a pump, but causing the sides of the tube to collapse, unless able to sustain at any given part, a compressing force proportioned to the column of water in the tube below.—When nature intends a tube to resist any degree of suction, the tube is made rigid in proportion;—witness the wind-pipe and its branches, which are the only instances in the human body. And if tubes prepared for sucking air only, and which are defended from external violence by surrounding parts, have received such rigidity, how much stronger would tubes for sucking blood have been?

Some bad reasoners on this subject have believed, that if a suction power exist, capable of lifting one inch of a column of liquid, any column, however long, must follow the first inch when acted upon by the power; for, say they, the atmospheric pressure by preventing a vacuum will prevent separation of the liquid. Now, in the first place, this reasoning is quite inapplicable to pliant tubes, because the ready collapse of their sides will both allow the separation, and prevent the vacuum; and in the second place, with respect to rigid tubes, it is equivalent to asserting that a force just capable of lifting one link of a chain, must therefore be able to lift any number of connected links.

steam-engine of a hundred horses power, and giving it his Lilliputian thrust, alternately backward and forward, were the prime mover of the machinery.

The truth explained above, that no kind of pump can lift fluid through pliant tubes, free to collapse, like the veins, renders it unnecessary farther to speak here of the pumping action of the heart itself, insisted on by Dr. Carson, or of that other action, mentioned in a subsequent part of this work, to which also he attributes great influence, *viz.* the tendency towards a vacuum external to the lungs and around the heart, produced by the disposition of the lungs to collapse. It may be remarked, however, that this last influence is more considerable than the simple inspiratory action dwelt on by Dr. Barry, and that it operates during expiration nearly as much as during inspiration, varying in force with the degrees of expansion of the chest. It is weaker in the living than in the dead body, because the rigidity of the distended pulmonary arteries helps to support the weight of the living lungs.

Were it necessary to give proofs, to persons unable to follow the above argument, that a suction power in the heart or chest is not the force which draws the blood from the extreme veins, the reference is ready to many notorious facts quite incompatibel with that supposition; such, for instance, as those recorded at page 448, and others. A vein tied, fills tensely below the ligature—a vein cut across bleeds from its distant orifice, and will fill a lofty tube connected with it—the circulation goes on in persons holding their breath, &c. &c.[*]

---

[*] The influence of inspiration, of the cavity in the chest exterior to the lungs, and of the expansive power of the heart, in the circulation of the blood in the veins, has no doubt been over estimated by Drs. Barry, Carson and others, but our author, appears to us to have undervalued their effect. Their joint power is more considerable than the reader might be led to suppose from the perusal of the preceding pages.

The influence of inspiration has been estimated by our author, perhaps justly, as only sufficient to raise a column one inch; if this force acted through *rigid* tubes of the length of the veins, it would produce no movement of the contained fluid; but acting through pliant tubes, it would raise one inch of the blood out of the vein nearest the heart, and if this power acted alone, its effect would here

After the explanations now given, it is almost superfluous to remark that *absorption* in animals cannot depend on atmospheric pressure, and that the effect of cupping-glasses applied to extract blood, or to prevent the absorption of poison in wounds,* in no way depends upon the fluctuating density of the air in the chest. Dr. Barry's reasonings upon these subjects involve the same fallacies as his reasonings on the venous current. With respect to absorption, they neglect the fact of fluids having weight; and with respect to cupping-glasses, of which the true action is explained at page 313, they are equivalent to asserting that the action of pumps drawing water from a river among the hills is influenced by tides, or pumps operating at its mouth in the sea.

---

cease. But the vis a tergo, produced by the propulsive power of the capillaries and perhaps also of the heart, prevents the collapse, the vein is kept full, and at every inspiration this power is renewed.

The influence of the tendency towards a vacuum external to the lungs, and around the heart, from the contractile disposition or the resilience of the lungs, is admitted by our author to be more considerable than the imparatory effort, and it in fact is we think greater than is suspected. We have some reasons for believing that the lungs do not entirely fill the cavity in which they are contained, the influence of this space is therefore constant, though greater during inspiration, and of course diminished during expiration.

The capillaries our author has most satisfactorily shown have a vital expansive power; and though he does not assert that the heart has no such power, he denies that it can have any influence on the movement of the venous blood, since it must act through pliant tubes. This would be the fact if the expansion of the heart were the only moving power, but the vis a tergo prevents their collapse, and the effect of the expansive power of the heart, whatever that may be, is allowed to act.

While therefore the action of the capillaries and perhaps of the left ventricle of the heart, must be considered as the main forces by which the blood is propelled through the veins, respiration, the resilience of the lungs and the expansive power of the heart; or in other words atmospheric pressure, ought to be viewed as an accessory force, though the precise power it exerts, we cannot readily estimate.

Am. Ed.

* The effect of cupping-glasses in preventing the absorption of poisons has been shown by Dr. Pennock to be owing to the mechanical pressure. See his interesting paper in the American Journal of the Medical Sciences, Vol. II.

Am. Ed.

If the fluids in animal vessels had no weight, it is true, that in absorption, an external atmospheric pressure of fifteen pounds per inch might force new matter into a receiving orifice, at the instant during inspiration, when the opposing pressure in the chest, at the other ends of the vessels, were half an ounce per inch less,—there would be no physical absurdity in supposing this, although there are physiological facts that disprove it—but when we reflect, that in all vessels under the level of the heart, the weight of the contained fluids causes an additional outward pressure of about half an ounce troy for every perpendicular inch of fluid column, making an excess of outward pressure at the toes, for instance, even at the most favourable time for absorption, of about two pounds per inch, we see that absorption must be a strong *action of life*, able to overcome a great excess of mechanical resistance, instead of a passive phenomenon obeying an excess of mechanical force. If a mere balance of pressures acted at the orifices, as Dr B. supposes, the blood and other fluids would be constantly oozing out from all orifices below the heart, as blood really does from an artificial opening, with force that would fill a tube reaching as high as the heart. It would be good news for proprietors of mines and others having to raise water, if by taking off an ounce or two per inch of the atmospheric pressure at the top of a full pipe, the continuing pressure elesewhere would then force water in at openings below, and cause an upward current:—but in truth, to make the atmosphere efficient below, powerful steam-engines or other means must be used to take off a pressure above, of at least half an ounce per square inch, for every inch in height which the water has to rise.

Another erroneous conception of atmospheric pressure, akin to that which we have been considering, is expressed in the following reasoning on the progress of blood in the veins. "The atmosphere presses 15*lbs.* per square inch on all things; the blood in a vein, therefore, which has 20 inches of surface, is pressed upon, through the flesh, with a force of 20 times 15. or 300*lbs.*, while a cross section of the vein near the heart would measure less than one inch. The blood, therefore, is always running towards the heart to escape from a powerful excess of atmospheric pressure."—This paradox is solved by the law of fluid pressure, explained at page 243. The same reasoning would prove that an eel-skin suspended by its lip, and filled with water, when exposed to the pressure of the atmosphere, should quickly run over, and be emptied; and nearly the same would prove that a long sharp wedge thrown into water, should be always moving in a direction away from its point; and that a ship formed like the wedge should make quick speed across the sea without either oar or sail.

A knowledge of the facts detailed under the three heads of *arteries*, *capillaries*, and *veins*, prepares us for the discussion of the following subjects.

The force of the Heart.

The arterial tension of four pounds to the square inch, marked by its supporting in a tube connected with the arteries, a column of blood eight feet high (*see page* 445,) is produced by the action of the heart; but as the heart, while injecting the blood against this resistance, has moreover to overcome the *inertia* both of the quantity injected, and of the mass in the great artery, first moved by the injection, as also the *elasticity* of the vessel yielding to momentary increase of pressure, the heart must act with a force of about six pounds on the inch. Now as the left ventricle of the human heart, when distended, has about ten square inches of internal surface, the whole force exerted by it may be about sixty pounds. It is remarkable that, with this easy means of solving the question, the correct and elegant Majendie, in his recent elements of physiology, should speak of it as undetermined; and should cite, as the best approximation, an estimate from the obscure circumstance of a loaded foot shaking in unison with the pulse, when suspended in the cross-legged sitting attitude.

The velocity of the circulating Blood.

This has been much over-rated. 1st. By assuming that the ventricles of the heart are completely filled and emptied at each pulsation:—an assumption disproved by inspection of the exposed heart of a living body, and by the fact of the valves between the auricles and ventricles not closing so perfectly as quite to prevent regurgitation. 2d. By supposing the issue of blood from a wounded artery or vein to be the measure of the usual velocity. Now it would be as reasonable to suppose the issue of water from a wounded pipe connected with any resorvoir to be the measure of a continued current in that pipe, although in truth, the issue would be the same even if the water in the pipe were usually at rest. 3d. By supposing the *frequency* of the pulse to be a measure. Now we know, that in diseases of debility, and in animals bleeding to death, the pulse usually becomes more frequent as it becomes more feeble, and as there is less blood moving. 4th, and lastly. By supposing the *strength* of the pulse to be the measure. Now we find that the pulse in an artery just tied, and where consequently there is no current at all, is scarcely weaker than in an open artery. The common fact of a person's feet remaining stone-cold for hours, although the arteries leading to them pulsate nearly as usual, is a proof that exceedingly little blood is passing through the capillaries at the time, and that the pulse, therefore, is no measure of its speed.

The ventricles of the heart appear, under common circumstances, to throw out about an ounce and a half of blood at every contraction—or about seven pounds per minute. Now if the body contain about twenty pounds altogether, as seems to be the case, the whole would circulate twenty times in an hour. This would give an average velocity of about eight inches per second in the aorta, but gradually less in the smaller arteries, because whenever a vascular channel subdivides, the branches taken collectively have considerably greater area than the trunk from which they arise, and the current diminishes in a corresponding proportion,—just as the speed of a river stream is always less in the parts which are deeper and broader. The velocity in the extreme capillaries is found to be often less than one inch per minute. In the veins, the blood must move more slowly than in corresponding arteries, in proportion as the veins are more capacious than the arteries.

The pulse.

The opinion which the ancients held, that the arteries contained *vital spirits* or *air* and not *blood*, rendered the pulse, to them, a very mysterious phenomenon; and many curious hypotheses were framed to explain it. These it would now be unprofitable to detail. Even Harvey's grand discovery of the circulation, however, has not rendered the subject so simple as might have been anticipated. The following opinions now exist, or have lately existed, with respect to the pulse.

1st. The great majority of physiologists have believed that a tumefaction is produced in the aorta by each jet of blood from the heart, and spreads afterwards as a wave into all the arterial branches. 2d. Many have supposed a contractile action of the arteries themselves, corresponding to that of the heart. 3d. Bichat, unable by any means to detect the slightest change of diameter in the arteries during pulsation, but perceiving that in many situations they were at the time somewhat lengthened, so that straight portions became bent, and originally bent portions were bent still more, held that this locomotion of the arteries was the cause. 4th. Others have supposed the impulse of the heart's contraction to be transmitted through the fluid blood, somewhat as sound is transmitted through bodies generally, or as a blow struck on one end of a log of wood, is felt distinctly by a hand applied to the other, although there be no visible locomotion. 5th. Dr. Young, in the paper in the Philosophical Transactions already alluded to, has shown that a sudden rush forward of the blood in the artery, such as might be produced by injection at one end of a rigid tube, would be felt by a finger applied, quite as distinctly as a tumefaction; and he deems this occurrence to be a chief cause of the pulse. Dr. Parry, in his work on the pulse, points to this almost exclusively as the cause.

Now the truth is, that the pulse in the living body does not depend upon any one of the particulars just noticed, but has all of them as elements; and its fluctuations and varieties depend upon the proportions in which these elements are combined. We shall review them again to prove this.

1st. At each jet of blood thrown into the aorta, a tumefaction or wave *must* spread from the heart to the extremities; for it is evident, that if blood be at all pushed into the arterial system, it either must dilate it, or cause an equal quantity to be expelled at the same instant from the distant extremities: now as the passage of blood through the capillaries appears perfectly uniform, there must be an intermediate dilatation. Dr. Parry and others should not have denied this dilatation because they could not see it: for even if its advancing front were more considerable than it is, because it passes almost with the velocity of a shock of electricity, it could no more be visible than a cannon ball crossing before the face.

2d. Contraction of the arterial coats certainly does not take place in the manner, and to the extent supposed by some who have spoken of it as resembling the contraction of the heart itself, and as what might be a substitute for the action of the heart in propelling the blood; but, as shown at page 440, the rigidity of tube which causes the pulse to be transmitted so quickly in all degrees of arterial dilatation, can depend on nothing but a contraction. There are some reasons for doubting whether this rigidity may not increase at the moment of the pulse.

3d. Unless the arterial tubes were absolutely inelastic, which they are far from being, they *must* be lengthened a little by a sudden injection of blood, and therefore, at all the curvatures particularly, there *must* be a degree of locomotion, often sensible to a finger applied.

4th. That a tangible shock is conveyed through a fluid without any apparent accumulation of it or change of velocity, and much in the manner of sound, is proved by the facts, that we may discover the working of a water-pump at very great distances, through iron pipes connected with it, and even through elastic pipes of leather, as those of a common fire-engine, from which the water is spouting nevertheless, in a uniform stream. The pulse in a tied artery, in which there is no current or rushing wave, must be chiefly from this cause, and from the locomotion of the artery.

5th. That any additional quantity of fluid injected into elastic vessels already full must spread all over with a *forward rush*, affecting the finger of an examiner as described above, is also most certain. As the heart, however, often beats without discharging much of its blood, and as in many arteries, from inaction of the capillaries, or pressure, the blood for a time makes little or no progress, while the pulse, however, remains very distinct, the pulse in such cases must be produced independently of the forward rush. An animal intestine prepared, and filled with water or air, and laid upon a table—or a full vein in the living body, carries a rapid and distinct pulse to a great distance when gently tapped by the finger. The cause of the sensation, then, cannot be the simple forward *rush* without tumefaction, described by Dr. Young and Dr. Parry.

In whatever proportions these particulars combine to form the pulse, its force will be proportioned to the size of the artery.* Hence as an artery leading to an inflamed part becomes of greater caliber, its pulse also becomes stronger.

It is a remark respecting the pulse, appearing to the author worthy of deep consideration, that if the purpose of the heart and arteries were merely the propulsion and conveyance of the blood, their structure and action would form most signal deviations from the ascertained rules of fitness in mechanics. In machines of human contrivance, it is one of the most important maxims "to avoid all shocks, or jerking motions;" and in former parts of this work, we have described fly-wheels, air-vessels, springs, &c. as means of accomplishing this, and thereby, of preventing the tearing and straining of parts which would else happen. In the human body, also, we have had to describe the beautiful elasticity of the spine, of the arch of the foot, of the cartilages of joints, &c., as contrivances answering the same ends: and to remark that, in other cavities than the heart, which are alternately filled and emptied like it, as the stomach, bladder, uterus, &c., there is smooth and gradual action. The heart alone is the rugged anomaly which, from before birth until the dying moment, throbs unceasingly, and sends the bounding pulse of life to every part: and which moreover, instead of being secured and tied down to its place, is attached at the extremity of the aorta, like a weight at the end of an elastic rod or plank, and every time that it fills the aorta, it is thrown with violence, by the consequent sudden tendency of the vessel to become straighter, against the ribs, in the place where the hand applied feels it so distinctly beating.

---

* Experience points out so strongly the incorrectness of this remark that we are surprised our author should have ventured to make it. It ought always to be borne in mind that arteries are *living* machines. Every one having any experience, must have felt the pulse large and soft, with a feeble beat, and also small and hard and with a strong beat. AM. ED.

Now one use of the pulsation of the heart probably is, by the *agitation* and *churning* which the blood suffers in passing through it, to keep in complete mixture all the heterogeneous parts of the blood, and which so readily separate when left to repose:—but this cannot be the only use, for the object might have been more simply attained; and we may conclude that the phenomenon has relation to some important law of life still hidden from us. The cause commonly assigned for the heart's contraction is the stimulus of the blood; yet if we reflect that the heart will beat after removal from the body, and when it contains only air; and that during life it beats with extraordinary regularity, whether the state of the circulation allow it to empty itself at each beat or not, we perceive that the cause is more obscure. We cannot contemplate this subject attentively without perceiving a strong analogy between the action of the heart and some electrical phenomena in which there are successive accumulations and exhaustions of power; and, recollecting the important relations which late researches have shown to exist between electricity and certain actions of life, the inquiry becomes more interesting. Galvanism can excite the muscles to their usual actions; it effects the secretions and the digestive function, and the breathing in asthma; strong animal passion seems to produce electrical excitement; and certain animals have the faculty of stunning their enemies by an electrical discharge. The pulse, then, in its sudden, strong and regular recurrence, may be a kindred phenomenon. In this view, there would be less difficulty in supposing a momentary stiffening or slight contraction of the whole arterial system, such as the sudden rising of the mesenteric arterial tree so readily suggests; if there be such, however, it is still dependent on, and proportioned to, the action of the heart; for it occurs only with that of the heart, it indicates any disturbance of the heart's action, and at death, it ceases in the remote extremities first.

The preceding considerations exhibit the pulse as a complex subject, and one on which professional opinions are not yet settled. By showing its close relation to the powers of life, they also prove it to be an object of high importance to the medical practitioner. This last truth has scarcely been questioned but by persons either utterly uninformed, or singularly deficient in the power, of tactile discernment; yet, because no simple and good analysis of the pulse, and detail of its relation to morbid states, has been produced, the degrees of skill with respect to it acquired by individual practitioners is very various, and in a great measure accidental. Some try the pulse merely for form's sake, because patients expect it; many examine it only to count its frequency; but others read in it, with confidence, much of the history and probabilities of the disorder, and decide on the treatment accordingly. Few who have attended to the subject at all, can confound the pulses of such diseases, as acute rheumatism, gastric inflammation, the fits of ague, &c. The author remembers to have conversed with a Chinese practitioner who had only the scanty medical information of his countrymen, but who judged by the pulse with singular penetration.

The changing circumstances in the state of the circulatory system, connected with health and disease, and discoverable by a finger watching the pulse, seem to be chiefly the following; and the epithets added in italics, are those which seem best, to indicate the sensations perceived.—The artery at the wrist is that generally chosen for examination, because it is covered only by skin, and has nothing between it and the bone below.

1st. The number of the contractions of the heart in a given time, and the regularity of their recurrence.—Pulse, *frequent, slow, intermittent, equal, regular, of varying force.*

2d. The degree of the heart's contraction, or the quantity of blood ejected at each time; and the corresponding state of the capillaries as to the quantity of blood passing through them.—Pulse, *full, long, labouring, bounding, feeble.*

3d. The force of the heart's action, with the correspondent arterial tension or rigidity.—Pulse, *hard, sharp, strong, wiry, weak, soft, yielding.*

4th. The suddenness of the individual contractions of the heart, and the rigidity of the vessels in conveying the shock.—Pulse, *quick, tardy.*

5th. The size of the artery for the time, whether larger or smaller than usual.—Pulse, *full, large, strong, small, weak.*

Superficial as is this sketch, it may show that a good treatise on the subject of the pulse, as connected with disease, is yet a desideratum in medicine. The sort of empirical, but useful tact which many persons acquire, is not fitted to satisfy the reasoning physician; whose mind should have always present to it the various constituents of the pulse, and all the important circumstances of health or disease related to its indications. The laboured treatices of *Solano, Bordeu, Boerhaave,* &c. may treat of what were clear ideas to their authors but by not referring to the physical causes of many varieties, they become so obscure to others, that many of the divisions and denominations appear altogether fanciful. Dr. Young's excellent paper in the Philosophical Transactions details important facts, as far as it goes, but it was not intended to point out all the pathological relations. Dr. Y., guided by general principles, asserted a progressive motion of the pulse, while other authors were holding it to be quite simultaneous over the whole system. He might have mentioned in proof, that careful examination can practically detect the succession of beats, particularly at the four stations: 1st. of the heart; 2d. in the lip; 3d. at the wrist; 4th. at the ancle:—but the interval of time, even between the extremes, being only a small part of a second, persons will often fail to make their first experiment satisfactorily. Dr. Parry's treatise on the pulse, which is the last one of note, although having excellencies, errs—in attributing the phenomenon to one cause too exclusively—in denying arterial dilatation, because it was not discovered by his mode of searching for it,—in supposing that a liquid column in an elastic tube can be made to advance like a solid rod, or a line of billiard balls. The too common neglect of mechanical philosophy by medical men, is signally proved, by our finding in works of authority, published at the present day, such statements as that the arterial pulse may be more frequent or less frequent than the beatings of the heart. *Dr. Good* (*study of medicine*) says, that there may be various frequency of pulse in various parts of the body at the same time; *Richerand* (*physiologie*) says, the pulse is more frequent in the artery leading to a whitlow than at the same time elsewhere; and many practitioners share these notions. What a satire on the medical profession is this disagreement, on a point which to common observers seems above all others to occupy the attention of the attendant on the sick!

Having now explained the circulation of the blood in general, we proceed to consider some cases where mechanical circumstances modify it.

Circulation in the Head.

The head may be considered as an air-tight vessel or cavity of bone, containing chiefly brain and blood, and having openings which admit blood-vessels leading to and from the heart. The atmospheric pressure, therefore, always keeps the head full, as it keeps the top of a syphon full; and because the substance of the brain itself does not sensibly change in bulk by any ordinary degree of pressure, their must always be the same quantity of blood in the head, how much soever the quantity may vary in the body generally. Regard to this important truth, a knowledge of which has followed the discovery of the true nature of atmospheric pressure, enables us to explain many hitherto obscure facts, both in health, and in disease;—as the following instances will show.

If from any cause the arteries in the head become too full of blood, in the same proportion the veins must become too empty; or, if the veins be too full, the arteries must be too empty: and in either case the circulation in the head will be in a corresponding degree impeded, because when one part of a channel is narrowed or diminished, the current throughout the whole is slackened. Now as insensibility supervenes when the supply of fresh blood to the brain is interrupted, and death follows if the interruption continues long, it seems evident that in many of the cases of apoplexy, where, on inspection, there is found nothing but a fulness of the arterial or of the venous system of the head, death has happened merely because the circulation was arrested in this way. In other parts of the body, not circumstanced like the brain, an excess of blood in one set of vessels may happen with perfect impunity to the individual.

Simple increase of pressure produced by the blood on the brain, provided the proper balance exist between the quantity in veins and arteries, has no injurious effect. This is proved by the safe descent of a person in the diving-bell, where at thirty-four feet under the surface of the water the body is bearing an additional pressure of fifteen pounds on the square inch (see page 291,) which pressure through the blood-vessels affects the brain as much as any other part.—On the other hand, when a man climbs a mountain, or ascends in a balloon, the brain is less pressed than usual; but the proper balance of artery and vein being maintained, no inconvenience is felt. The inhabitants of some of the valleys among the Andes are as far above the sea as they would be at the top of Mont Blanc, where the atmosphere presses only half as much as on the sea-shore, but they enjoy good health.

As the box of the cranium encloses the brain so as to leave no vacant space, it is evident, that when the heart injects blood with unusual violence, the strain at first is chiefly borne by the cranium, and not by the coats of the blood vessels. Hence the arteries of the brain are not nearly so strong as those of other parts of the body.

The veins of the brain are also peculiar. Common veins in the head would collapse by any sudden tension of the arteries and if they did, insensibility or death would ensue, on account of the consequent stoppage of the circulation. The chief channels, therefore, for the refluent blood, instead of being common compressible veins, are what have been called *sinuses*, or grooves in the bone itself, with exceedingly strong membranous coverings, supported so powerfully, that the channels become in strength little inferior to complete channels of bone. This singular deviation in the structure of the cerebral veins from that found elsewhere, and without which deviation animal existence could not be continued, is one of those particulars which powerfully affect the contemplative mind, as proofs of the designing intelligence which has planned this glorious universe.

From not adverting sufficiently to the fact which we are now explaining, of the cranium being a vessel always full, and which will hold only a certain quantity, misconception has prevailed among medical men with respect to many of the affections of the brain.

It has been said, for instance, that the substance of the brain cannot bear pressure with impunity, for that stupor immediately follows it, however produced. Now the truth is, that pressure produces stupor only when it interferes with the circulation. In wounds with loss of a large piece of the cranium, the brain will bear very rough handling, because if compressed at one part, it may bulge in another, and leave the circulation free. But if the wound be small, pressure made through it instantly affects the whole brain, and the blood from below it prevented from entering.—Let one reflect for an instant on what happens to the fœtal head during parturition,—how often it escapes elongated and bent, almost as it were of soft clay—yet the child lives and thrives, and the natural form is soon recovered.—The reason is, that the fœtal skull is soft, and pressure in one part is relieved by a corresponding bulging or extension in another, and the blood is not expelled.

Water in the head, again, is said to kill by this fatal pressure on the tender brain: but in reality, it kills by mechanically arresting the circulation. Accordingly we see, that where the *fontanelle* still remains open, or where the *sutures* or joinings, of the skull will yield, water may accumulate to a great degree without causing disturbance.

A tumour in the brain, which would be of no consequence if the brain were unconfined, soon becomes fatal by occupying room in the skull, and in the same degree excluding or checking the supply of blood.

If the substance of the brain at all increase and diminish in bulk, as muscles, &c, under certain circumstances, do in the body below, all such changes must produce a considerable effect on the cerebral circulation and functions.

Effects of position on the circulation.

While a man is in a standing attitude, the heart and arteries have to send the blood up to the head against gravity: but in the horizontal position, the blood if equally propelled, must arrive with greater force, because gravity then does not resist. Hence head-ache or other symptoms arising from fulness of blood in the arteries of the head, is often relieved by the upright position, and is increased by lying down.

Many people who have had a slight degree of tooth-ache during the day, find it intolerable when they lie down at night, and are relieved again by rising and walking about. Commonly they suppose that it is the cold which then lulls the pain; but it is in fact the change of position. The author knew one lady who was obliged to sleep for months in the sitting posture, because she had a *tic douloureux* in the face whenever she lay down, and another who was under the same necessity for a considerable period after an inflammatory affection of the brain, because if her head fell low during sleep she was immediately assailed by a terrific dream of swords driven into the brain.

Delirium in fever is sometimes checked at once by elevating the head. On account of the great relief thus obtained, some continental practitioners have proposed to support patients occasionally in an upright posture.

Apoplexy has often been brought on by a man bending his head down in the act of tying his shoe, or pulling on his boot.

Children and tumblers being much in the habit of placing their bodies in all positions, feel no inconvenience from having the head downwards; apparently, because arteries and veins always become strong enough to bear the pressure to which they are habitually exposed; but to many old people accustomed to keep the head always up, the attempt would be fatal.

Ulcers on the legs are often obstinate and will bleed, because the veins about them are too weak to support the lofty columns of blood above. Hence the frequent counsel given in such cases to keep the feet raised upon a chair.

Many inflammations of the legs and feet become exceedingly painful when the limbs are in a hanging position, and the pain is relieved by laying them horizontally.

Many anasarcous or dropsical affections of the legs increase towards night, because during the dependent position of the legs through the day, the absorbents want power to lift the fluid. The swelling disappears again before morning.

When the heart has to send blood upwards, it acts more strongly than when the body is horizontal, and the pulse increases five or six beats in the minute: hence the common rule to make a patient with hemorrhage lie in the horizontal position, that the heart may become tranquil, and allow the bleeding to cease.

Fainting from diminished arterial tension.

Fainting, which is a temporary cessation of the action of the heart, and thence, as explained above, of the action of the brain, is produced by several causes, and among others, by any occurrence which renders the blood-vessels about the heart suddenly less full or tense than usual. It would appear that the heart being accustomed, when it contracts, to a certain degree of resistance, has its action disturbed when the resistance is much diminished.

Thus hemorrhage, from any cause, by lessening the general tension of the sanguiferous system, often causes fainting. The state is relieved by lying down; probably because the still remaining weaker action of the heart is sufficient to send blood to the head along a horizontal course, until the gradual contraction of the whole vascular system reproduces the tension necessary to perfect action. A small quantity of blood taken away *suddenly*, affects the circulation as much as a larger quantity taken *gradually*, apparently because a certain space of time is required for the gradual lessening of vessels.

The operation of *tapping* for dropsy in the abdomen, would often bring on fainting, but for the precaution of tightening a broad bandage upon the body as the water flows. The reason is, that the sudden removal of a large quantity of fluid which had been compressing all the abdominal vessels, and keeping them perhaps only half full of blood, allows them again suddenly to receive their natural quantity, and thus produces a relaxation of the other parts of the vascular system.

Sudden parturition often causes faintness for the same reasons.

Even rising up suddenly from a horizontal position on a bed or couch will cause an approach to fainting in weak people, or in those who have been long bed-ridden: probably because the heart having for a time been accustomed to send blood only in a horizontal direction to the head, does not in an instant exert the additional power required to lift an upright column with equal force;—besides that the blood does not then return to the heart, by the veins, from the inferior parts of the body, so readily as before.

These various facts, now easily understood, form the reason of a rule which is a great modern improvement in the practice of the healing art, *viz.* in bleeding for the cure of inflammation, to take the blood away as *quickly* as possible. This subject deserves a little farther consideration.

A great proportion of dangerous diseases involve inflammation of some vital organ; and inflammation consists chiefly, as already stated at page 444, of a gorging or over-distension of the capillary vessels in the part. The nature of the capillaries, again, is such (page 443,) that when not maintained constantly full by the pressure of the heart behind them, they gradually, by their own action, empty themselves towards the veins,—as is seen in the disappearance of a local inflammation soon after the death of the person; or in the fact of the arteries being emptied of blood after breathing ceases, &c. Now ever since medicine deserved the name of an art, practitioners have accounted the lancet their sheet-anchor in inflammatory disease; but it is only in late times, since the circulation of the blood was understood, that they have known the rationale of the remedy, *viz.* that it acts by diminishing vascular tension, and hence the action of the heart, and so allowing the small vessels to empty themselves by their own force, and to recover sufficiently to resist the return of an excessive load. It is still more lately that they have understood, how much more suddenly and completely the disease is cured by abstraction of a small quantity of blood *so rapidly*, as to produce fainting, than of a much larger quantity *so slowly* that only weakness follows. Judicious treatment now cures inflammation much more certainly and completely than was done formerly, yet with much smaller loss of the precious blood, and with less danger of those diseases of weakness, or of that complete breaking-up of the constitution, which often follow great depletion. To induce faintness, *large* openings are made into the veins—sometimes into two veins at once, and the patient is kept in the upright attitude. Often thus an inflamed eye, which was as red as scarlet before bleeding, in a few minutes is rendered nearly of the natural appearance; and intense inflammations of the brain, lungs, bowels, &c. are removed in the same manner. In all these cases the faintness seems to be equally efficacious, whether it happens after the loss of ten ounces of blood, or of fifty; or even, as sometimes occurs, when it happens without bleeding at all, after merely tying the arm in preparation.

Reflection upon these circumstances led the author to think that, in certain cases, the beneficial effects of blood-letting might be attainable by the simple means of *extensive dry cupping*, alluded to at page 313; that is to say, by diminishing the atmospherical pressure on a considerable part of the body, on the principle of the cupping-glass used very gently, and thus suddenly removing for a time from about the heart, a quantity of blood, sufficient by its absence to produce faintness. The results of trial have been such as to give great interest to the inquiry, and the author's leisure will be devoted to the prosecution of it. —An air-tight case of copper or tin plate being put upon a limb, and made air-tight by a leathern or other suitable collar tied round its mouth and the limb with bandages,—on part of the air being then extracted by a suitable syringe, in an instant the vessels all over the limb become gently distended with blood; and as the blood is suddenly taken from the centre of the body, faintness is produced, just as by bleeding from a vein. The excess of blood may be retained in the limb as long as desired, for the circulation is not impeded. To produce a powerful effect with a slight diminution of pressure, more than one limb must be operated upon at the same time.

An instrument resembling the contrivance now described, was proposed about twenty years ago by a non-professional person, as a means of drawing all sorts of diseases out of the body through the pores of the skin. He enclosed a leg in an air-tight case; he then admitted steam to heat the limb, and relax the pores of the skin, as he said, and then he worked an air-pump to draw out the disease. He called the engine the *air-pump vapour-bath*. In various cases where its true action was desirable, although not understood by the proposer, nor judiciously managed, it proved beneficial.

The operation of applying tourniquets or bandages round the limbs, so as to prevent the blood from passing easily to and from them, affects the action of the heart. It is said sometimes, to have prevented the accession of ague. It is a means akin to those above described.

Because arteries are stronger than veins, a bandage may be put round a limb, tight enough to close the veins but not the arteries, and the limb will then swell beyond the ligature. By thus putting tight elastic bandages round all the limbs at once, and immersing them in warm water to favour the dilatation of their vessels, so much blood may be suddenly detained in them as to cause the person to faint. Such a means, therefore, might also be used remedially.

In the same way, a tight handkerchief, or stock round the neck, will often retain the venous blood in the head, and cause apoplexy.—Strong pressure made on the jugular veins kills as certainly as if made on the windpipe.

When a *hernia* or other tumor is strangulated, it swells, and if not relieved, it soon mortifies.

Diffused pressure, like that made by rolling a bandage round a whole limb, or by immersing the limb in fluid, must affect the circulation. The veins will be more compressed than the arteries, by reason of the distended force in them being less. Varicose veins, therefore, are usefully supported by a bandage or laced stocking. The reason why this manner of supporting assists so powerfully in the healing of ulcers on the legs may be, that the support affects the capillaries and absorbents as well as the larger vessels.

Poultices, by their weight, produce a soft compression of the parts on which they are applied; and in certain cases, may benefit by mechanically squeezing the excess of blood out of weakened vessels.

The author has relieved the chronic inflammation of a sprained ancle, by ordering the foot and leg, covered with an oiled-silk stocking, to be enclosed in a boot strong enough to support the pressure of quicksilver, and to be then surrounded by this for an hour or more.—The effect is a pressure by the fluid metal on the weak vessels, of one pound to the square inch, for every two inches of the depth of metal above the part.—A height of four or five inches gives the relief expected. A much greater elevation would stop the circulation altogether. No bandage can press with uniformity approaching to this action of a fluid.

The effect of continued pressure, in removing morbid tumours of various kinds, is explicable on the same principle. The author doubts not that in such cases, pressure properly managed, would prove a much more valuable remedy than is at present generally supposed. The elastic steel half-hoop, with one cushion before and another behind, lately introduced for the relief of hernia, affords an admirable mode of producing a uniform pressure of any desired force upon the female breast.

When a man stands in a bath, with the water up to his chin, there is a pressure of the water upon his body, proportioned every where to the depth (see page 242.) This pressure must produce a considerable effect on the blood vessels of the lower parts of the body. We see in this that a bath must propel the blood from all the external veins of the body towards the cavity of the chest, which the pressure cannot reach: it is this effect which in part causes the feeling of thoracic oppression experienced by persons on first plunging into water, which feeling is usually attributed altogether to the cold.

The old practice of placing a patient in a pit, and surrounding his body with earth or sand, must have had a mechanical action of the kind now contemplated, in addition to any other influence.

Transfusion of blood from the vein of a healthy person, into that of one fainting or dying from hemorrhage, is in operation the converse of some of those mentioned above. It has been frequently performed with success. The cases best fitted for it, are those of flooding after parturition, and of wounds; and there can be no doubt that many of the lives lost from these so frequently recurring causes, might be saved by its adoption. The blood to be injected is received into a vessel, as in common bleeding; from which vessel, by a fit syringe (see page 499,) it is transferred as it flows, into an open vein of the patient. The admission of air with the blood would be fatal, and has therefore to be most carefully guarded against. The last interesting report upon this subject is that of Dr. Blundell, in his Physiological Essays.

RESPIRATION AND VOICE.

The doctrines of fluidity, illustrating and illustrated by the animal respiration and voice.

As the motion of a windmill depends altogether on the breeze to which its vanes are exposed, so does the motion and the life scarlet colour, and thence departs to carry new life to the general system.

The minute vessels through which the circulating blood is strained in the chest do not hang loose in the cavity, but are supported by running through spongy masses, called the lungs, which consist chiefly of vessels and of thin membrane formed into cells. The cells at every inspiration receive fresh air through the cartilaginous wind-pipe which branches into them, and at every expiration they return the changed air by the same channels to the atmosphere. The lungs of a child, before birth, are perfectly collapsed, or without the least air in their structure, and hence are dense enough to sink in water; but after breathing, they retain a portion of air, and will float. This fact has been accounted a test of whether a child had been born dead or alive; but as putrefaction, &c. will cause air to be in lungs which have never breathed, the criterion may be fallacious.

The chest is a large cavity bounded above and around by the ribs, back-bone, and sternum, and below, divided from the abdomen or belly by a strong membranous and muscular expansion, called the diaphragm. The ribs in the natural state, hang obliquely downwards from the posterior attachments to the spine, and on being raised in front, they widen or increase the size of the cavity, as already explained at page 214. The cavity is farther enlarged by the descent of the diaphragm, which may be regarded as both the floor of the chest and the roof of the abdomen, and which being naturally convex upwards like a dome, by contracting itself to a more flat condition, sinks out of, and enlarges the chest, while it descends into and diminishes the abdomen.

Now on the chest being enlarged by the rising of the ribs and descent of the diaphragm, or by either singly, the air rushes into it through the mouth and wind-pipe, exactly as air rushes into a common bellows through its pipe, when the valve is shut and the two boards are drawn apart; and air is again expelled from the lungs by the contraction of the chest, as from the bellows by the approximation of the boards. Into both cavities air enters, because with the enlarging dimensions, the air which was within dilates and becomes less powerfully tense or resisting against the external pressure of the atmosphere, and so allows more air to rush in to restore the equilibrium. The air is expelled again by the contraction of the cavities, because, by being compressed, its elastic force or tension becomes greater than that of the external air, which it therefore easily repels, and so escapes.—By immersing a common bellows in water and then opening and shutting it, the entrance and exit of the fluid is rendered very apparent.

That the air admitted to the chest should have the fullest action on the blood passing there, it was necessary that the spongy mass of lungs in which the blood vessels ramify, should occupy the whole of the cavity, and be equally distributed. Now while the equable distribution is effected by the uniform elasticity or resilience which belongs to the structure of *lung*, the complete filling of the cavity is obtained, not by general attachments between the lungs and the ribs or sides of the chest, as might be expected, but by the following means, equally simple, and yet more perfect. The spongy mass of the lungs is completely covered by a strong adherent membrane called the pleura, as close in its texture as a bladder: between this membrane and a similar lining of the chest there is no air or empty space, and therefore, in the rising and falling of the ribs during respiration, this membrane remains always in contact with them, just as a bladder put into a bellows as a lining, with its mouth secured around the nozzle, is filled and emptied, and remains in contact with the interior of the bellows, in all its states of dilatation, as if there were attachments in a thousand places.* This construction allows the lungs to have a singular freedom of play during all the motions of the body; a freedom farther provided for by their being divided into five portions or lobes, of which three occupy the right side of the chest, and two are in the left, the heart occupying in the left the place of the third. The right and left sides of the chest are formed into cavities quite distinct from each other by the *mediastinum*, a strong membranous partition. The mechanical disposition of the contents of the chest, as now described, is productive of certain consequences which it is important to understand,—for instance,

---

* It appears to us doubtful, that the lungs entirely fill the cavities of the chest, as asserted by our author; we suspect that the contractile disposition, or elasticity of the lungs prevents this. AM. ED.

If a wound be made in one side of the chest so as to admit air, the lungs of that side collapse in obedience to their weight and elasticity; and when the chest afterwards enlarges and diminishes in respiration, air more easily enters and leaves the space around the collapsed lung, through the wound, than it can enter or leave the lung itself through the wind-pipe; because in the first case it has no force to overcome, and in the second the elasticity, weight, and inertia of the lung oppose. If such a wound, therefore, were made into both sides of the chest at once, although without hurting any part within, the person unless assisted, would die of suffocation, because all the lungs would remain collapsed. The kind of assistance required in such a case, is to press the ribs down so as to empty the chest of air as much as possible, and then to keep the wounds close or covered while the ribs rise again; the air, of course, then enters by the natural road, the only one left, to fill the chest, and it distends the lung, and reaches the blood in the pulmonary vessels as usual. By preventing the breath from escaping by the mouth or nose, while straining with the muscles of the chest, as in the action of blowing, all the air which had entered by any wound in the chest may be expelled. In Benjamin Bell's system of surgery, which was long the manual of practitioners, from imperfect understanding of this subject, counsel was given the very contrary of that required; and, of course, any patient treated accordingly, must have been lost.

In cases of dangerous hemorrhage from a lung, after a wound in the side, the proper practice is to allow the lung to collapse, as now explained, that the hemorrhage may be checked; and when the danger is past, the external wound is to be closed, that the natural play of the lung may be re-established. Life may be supported for a time by the lung in one side of the chest.

In cases of hemoptysis, or spontaneous bleeding from the lungs, a disease so often fatal, life might sometimes be saved or prolonged by making an opening between two of the ribs, and allowing the lung to collapse. The affected lung is often clearly pointed out by the circumstances; and the opening, when properly made, would be no more dangerous, than in the case where, by a similar opening, water or pus is discharged from the chest.

The same operation has been tried as a forlorn hope in pulmonary consumption. This disease is often limited to the lung of one side, and as the alternate stretching and collapse of the diseased lung during respiration, together with the contact of the air, powerfully prevent an ulcer from healing, or inflammation from subsiding, a new chance of recovery is given by allowing the diseased lung to collapse and remain at rest.—Some cases are recorded where cure is said to have followed this operation, and certainly, where the circumstances are favourable for it, and where death must ensue unless it can save, it is worth trying.

When ribs are fractured, it is the practice to put a bandage round the chest, so as for the time to prevent the respiratory motion of the ribs, and the breathing is then performed by the rising and falling of the diaphragm or floor of the chest, as already explained: it bulges into the chest to lessen the cavity, and is again drawn down or flattened to increase the cavity. Although a person with broken ribs is obliged to submit to this unnatural restraint, it is surely the height of folly to inflict the same on healthy beings, as is yet, however, constantly done among young women, even to the destruction of their health, by the fashion of bracing the body in tight stays.

The force of a healthy chest's action in blowing is equal, as stated in last section, to about *one pound* on the inch of its surface; that is to say, the chest can condense its contained air with that force, and can therefore blow through a tube the mouth of which is two feet under the surface of water. In sucking or drawing in air, the power is nearly the same.—In both these actions it is possible to use the cavity of the mouth separately from that of the chest; and the mouth being smaller, with stronger muscles about it in proportion to its size, it can act more strongly. Some men can suck with the mouth so as to make nearly a perfect vacuum, or to lift water nearly thirty feet. In using the blow-pipe, an expert operator can keep up an uninterrupted blast by shutting the mouth behind while he inhales, and replenishing it as is required in the intervals.

In *coughing*, the *glottis* or top of the windpipe, by a curious sympathy of parts, is first closed for an instant, during which the chest is compressing and condensing its contained air, and on being then opened, a slight explosion, as it were, of the compressed air takes place, and blows out any irritating matter that may be in the air-passages; just as the burst from the chamber of an air-gun discharges its bullet.—This shutting of the *glottis* to allow the compression of the air, and its subsequent opening to allow the discharge, may occur at very minute intervals, and many times for one fill of the chest, as is instanced in hooping-cough.—The action of cough is often produced by irritation from a cause which cannot be removed by cough, as inflammation of the chest, or tubercles: or even by irritation in a distant part, as when children are teething, or when the stomach is overloaded.

Sneezing is a phenomenon resembling cough, only the chest empties itself with great violence at one throe, and chiefly through the nose, instead of through the mouth, as in coughing. The irritation that produces sneezing is generally in the nose; but as in the case of cough, sneezing may occur from distant sympathies: witness that from worms in the bowels.

Laughing consists of quickly repeated expulsions of air from the chest, the voice being heard with them; but there is never complete closure of the entrance to the windpipe as in coughing.

Crying differs from laughing almost only in the circumstance of the intervals between the gusts of air being longer. Children laugh and cry in the same breath, and it is often difficult to mark the moment of change.

Hiccup is the sudden stopping of a strong inspiration at its commencement.

In *straining* to lift weights, or to make any powerful effort, the air is shut up in the lungs, that there may be steadiness and firmness of the person. At such a time, by the compression and condensation of air around the heart and large blood-vessels, the blood is determined violently outwards from the chest, and often rises to the head, with force that produces giddiness, or even apoplexy:—the eye will become suddenly blood-shot, from a small vessel giving way during straining; and leech-bites will break out afresh.—The force of this pressure outwards is measured, as already stated, by a column of about two feet of blood; and this is therefore the measure of the additional arterial and venous tension in the body generally.

Suffocation is the name given to what happens when the supply of air to the lungs is in any way prevented. The blood, not then refreshed by the approach of the air, rises to the brain unfit for its purpose, and confusion of thought is immediately produced, soon followed by convulsion and death.

When that happens from mechanical obstruction at the narrow entrance of the windpipe, as in croup, by the tenacious films thrown off from the inflamed lining of the air-passages, life may be saved by making a new entrance for air through the windpipe lower down in the neck, and keeping it free by a little tube inserted, until the obstruction above be removed.—Where children die with croup, it is frequently not from the violence of the constitutional disease, but from detached films thus accidentally sticking in the narrow entrance of the air-passage.

In the cases of strangling and hanging, the tight binding of the rope or ligature crushes inwards the cartilaginous rings of the windpipe, and shuts the air-passage. It may also cause apoplexy, by arresting the passage of blood to and from the head: and there may be dislocation of the cervical vertebræ of the spine.

In *drowning*, communication with the atmosphere is cut off altogether by the supernatant water, and if the chest then expands, it can receive water only instead of air. The nerves and muscles, however, at the entrance of the windpipe, being exceedingly irritable, are excited by the contact of any unusual matter, and for a considerable time shut the passage against the intruding liquid. It is partly on this account that after immersion in water and apparent death, when the body is recovered within a moderate time, the life is often preserved.

The apparatus of the Humane Society for the recovery of persons apparently drowned, includes a bellows for producing artificial respiration. It resembles a common bellows, except that its flap or valve, instead of being internal as usual, is external like a large flute-key, with a spring to close it, and obedient to the finger of the operator. The bellows receives its charge of fresh air by being expanded in the usual way, while the valve is open; it sends the charge into the lungs on being compressed while the valve is shut; it withdraws the charge again on being expanded with the valve shut; and the impure air is thrown out to the atmosphere on its being compressed with the valve open. These changes repeated and continued, produce the artificial respiration required. It is most important to remark here, that if air be injected into the lungs, either in too large quantity or very suddenly, instead of recalling or sustaining life, it is as certain a means of killing as a dagger driven through the heart. This truth has been but lately known, and ignorance of it has probably decided the fate of many persons, treated with a view to recovery after submersion. The operator should reflect that he is dilating the delicate air-cells of the lungs with the force of an hydraulic press; and that if he do so very suddenly, although little, he still may rupture many small blood-vessels, before they can empty themselves so as to yield. In a bellows for the purpose of artificial respiration, there should be the means of checking its opening to suit the capacity of the patient's chest, and their should be a cock in the pipe or nozzle, to regulate the speed of the passing air.

In addition to artificial breathing for the recovery of suspended animation, it is often necessary to restore natural warmth to the body, to rub the limbs in aid of the circulation, to administer stimulants by the mouth, to excite by galvanism, &c.

It seems to be an error, and probably often a fatal error, in the present mode of treating persons apparently drowned, to

THE VOICE AND SPEECH.

The chest and air-passages, with certain additional parts, constitute the organs of voice and speech.

An inquirer into the constitution of the universe around him, meets with few things calculated more to surprise him, than that faculty in the human mind by which it can so closely associate the ideas of objects with any arbitrary signs that the ideas are afterwards excited by the signs almost as vividly as by the objects themselves. The inhabitants of China, for instance, having contrived many thousand grotesque characters, and determined what object each shall recall, a person who by study becomes familiar with them, may have his bodily eye poring over pages of crooked and unseemly scratches, while his mental eye is made to see only a pleasing succession of the most beautiful imagery of nature: and the characters are intelligible to the deaf and dumb man as well as to him who speaks, and they serve as media of thought and communication through many provinces and countries of which the spoken languages have no common resemblance.

If the ready remembrance of visible signs be wonderful, which have permanent existence, and often a certain resemblance to the things signified, how much more wonderful is it that an audible sign, that is, a passing sound or fugitive breath, should serve as well; and that by a succession of mere sounds, different in every country, and changing from age to age, any train of thought may be made to pass through the minds of an audience, so as to excite and to leave impressions almost as strong as from realities. Such, however, is the fact, and it is greatly owing to this and to a corresponding faculty of producing easily a sufficient number of distinguishable sounds, that man owes his elevation above the brutes of the field. His godlike powers of intellect would have remained dormant and unknown, had he wanted the power of comparing his invisible thoughts with those of his fellow men, and of arranging and recording them by means of signs.—Written language is a double remove from the objects themselves, being *visible signs* not of things, but of the *audible signs*.

The admirable apparatus by which man is enabled to produce a sufficient variety of sounds to answer his purposes, passes generally under the title of *the organs of speech;* because the combination of sounds which have meanings assigned to them is called speech. It consists of the chest for containing air, of the larynx or cartilaginous box at the top of the windpipe for producing the voice, and of the short tube of the mouth for modifying it.

In the chapter on acoustics, we explained that sound is the name given to the effect produced upon the ear by certain tremblings conveyed to it generally through the medium of the air; and we explained how air, rushing from the human lungs through the opening at the top of the windpipe, causes the elastic lips of that opening to vibrate, and to excite the tremblings. We have now to show that this sound, in passing forward from the top of the windpipe, may be modified at the will of the individual, in a great variety of ways—a variety which is however still very simple.

The modifications of voice easily made, and easily distinguishable by the ear, and therefore fit elements of language, are about fifty in number; but no single language contains more than about half of them. They are divisible into two very distinct and nearly equal classes called *vowels* and *consonants.*

Those of the first class are the simple voice issuing through the open mouth, and influenced only by the degrees in which the mouth is opened and elongated. They may be continued as long as there is breath to issue from the chest, and therefore are named *vowels* or *calling sounds.* The roman letters, A, E, I, O, U, as generally pronounced on the Continent of Europe, indicate the most easily distinguishable vowels. Sound passing through the mouth while in its most natural state of relaxation, is heard as the modification expressed there by the roman E: (or the *a* of the English word *care;*) if the mouth be then widened, it becomes A (of the English word *bar;*) if the mouth be narrowed, we hear I (or *ee* of the English *seem;*) if the mouth be elongated and at the same time widened, we hear O (of the English word *bore;*) and if elongated and narrowed, we hear U (of the English *rude.*) The possible number of vowels, however, is as great as the possible degrees in which the dimensions of the mouth may be altered. About twenty of them are sufficiently distinguishable, but few languages comprehend more than twelve. Modern art has produced the vowel sounds mechanically by means of tubes of certain dimensions.

The alphabets of Europe are very faulty in not using the same characters for the same sounds, and in not having a character for each sound, according to the true intent of an alphabet. In English one letter is used for several sounds, as A in *water*, *far*, *fat*, *fate*, which are four sounds perfectly distinct. In repeating the English alphabet, the A is pronounced as the broad E of the Italians and of Europe, and the E as the I; the English vowel I, is the diphthong AI of more correct alphabets: and the English U, is the diphthong IU. In consequence of the changes which have taken place in England in the meaning of the roman letters, the natives experience increased difficulty in learning modern continental languages; and their pronunciation of the ancient languages is ridiculous, and almost unintelligible to all but themselves. The same cause renders the pronunciation of English difficult to foreigners, and thus restricts much, in other countries, the cultivation of English literature.

To explain the second class of the modifications of sound, called *consonants*, we may remark, that while any continued or vowel sound is passing through the mouth, if it be interrupted, whether by a complete closure of the mouth, or only by an approximation of parts, the effect on the ear of a listener is so exceedingly different, according to the *situation* in the mouth where the interruption occurs, and to the *manner* in which it occurs, that many most distinct modifications thence arise. Thus any continued sound as A, if arrested by a closure of the mouth at the external confine or lips, is heard to terminate with the modification expressed by the letter P, that is, the syllable AP has been pronounced; but if under similar circumstances, the closure be made at the back of the mouth by the tongue rising against the palate, we hear the modification expressed by the letter K, and the syllable AK has been pronounced; and if the closure be made in the middle of the mouth by the tip of the tongue rising against the roof, the sound expressed by T is produced, and the syllable AT is heard, and so of others. It is to be remarked, also, that the ear is equally sensible of the peculiarities whether the closure precedes the continued sound or follows it: that is to say, whether the syllables pronounced are AP, AT, AK, or PA, TA, KA.—The modifications of which we are now speaking, appear then not to be really sounds, but only manners of beginning and ending sounds; and it is because they can thus be perceived only in connexion with vocal sounds that they are called *consonants.*

Now in the mouth considered as a vocal tube, there are three situations, in which interruption of voice or breath may most conveniently be made, and there are six modes of making it at each; so that eighteen distinct interruptive modifications or consonants hence arise. These we shall now describe.

The three great *oral positions,* as they may be called, are,

1st. At the external confine of the mouth, or lips, giving the *labial* articulations.

2d. In the middle of the mouth, where the tip of the tongue approaches the palate behind the teeth, producing the *palatal* articulations.

3d. Near the back of the mouth, where the body of the tongue approaches the palate, giving the *guttural* articulations.

The *six modes* in which the voice or breath may be affected in passing through each of the three positions of the mouth, are the following:

1st. *A sudden stoppage,* producing what may be called a *mute* articulation: *viz.* P, in the labial position; T, in the palatal; and K, in the guttural. (See here the general table of articulations at page 491, which table may be considered as representing the tube of the mouth, with the letters so placed in it as to show in what situations they are severally produced.) A mute may also be made by stopping the breath exactly at the teeth, producing thus a *dental mute;* but it is hardly distinguishable from the *palatal mute* just behind it, and being less perfect, is not used.—Some awkward speakers substitute it for the proper mute, and are said to *speak thick.*

2d. A sudden shutting, as in the last case, but the voice being allowed to continue until the part of the mouth behind the closures be distended with air. This produces the *semi-mutes,* B, D, and G, (in its hard sound as in *pig,*) for the three positions. There might be a dental *half mute,* but it is no more used than the *dental mute,* and for the same reasons. If the sides of the tongue be depressed after it has taken the position required for D, the sound L is produced.

3d. The positions closed as for the mutes, while sound is allowed to pass by the nose.—Thus arise the *semi-vowels* or *nasals,* M, N, NG, for the three positions.—NG, (as in *king*) is a simple sound, although our imperfect alphabet has no single letter for it. The nasal sound of the French language, which gives it so great a peculiarity, approximates to the English NG, but differs from it in the sound passing by the mouth, as well as by the nose. It is signified by *on* in the table.

4th. Breath only (or whisper) allowed to pass at the three oral positions nearly closed.—Hence come the sounds which we call *aspirates, viz.* F, TH, and CH, the two latter are simple sounds although expressed in English by two letters. The TH is heard in the word bath, and is the ϑ of the Greeks. The CH is heard in the Scotch word *loch;* in the German, *ich,* and is the χ of the Greeks. The *soft palatal aspirate* TH, is not so easily made as the *dental,* which is heard on pressing the tongue gently against the teeth, and allowing the breath to pass all around: the *dental,* therefore, is used in preference to the *palatal.* The letter S is the *hard palatal aspirate,* and differs from the *soft aspirate* TH, in the breath being made to issue with greater force, and only by a narrow space over the centre of a rigid tongue, instead of on all sides of a soft tongue, as for TH. French people, on first attempting to pronounce

TH, substitute for it the S, or the Z (which is nearly related to S, as explained below.) The author has found it easy to enable them to pronounce the TH at once, and perfectly, by explaining its nature as above. If we depress the sides of the tongue while pronouncing S, we make the simple sound expressed by the English double letter SH; just as by depressing the sides of the tongue while making D we produce L.

5th. Using *voice* in the same manner as *breath* or *whisper* for the aspirates.—This produces the sounds called *vocal aspirates, viz.* V, TH, Z, J, and GH. TH *vocal aspirate,* is heard in *bathe,* as contrasted with the *simple aspirate* in *bath;* Z comes from the S position, only with *sound* instead of *breath;* SH pronounced with *voice,* becomes the J of the French in the word *je,* or the sound heard in the middle of the English word *vision.* GH is a simple sound used in German, but not in English.

6th. Shaking the approaching parts in the three positions.—We thus make *vibratory sounds,* of which the middle position gives the common R, the only one of them used in England. Some bad speakers of English, however make the *labial vibratory* by shaking the P in such words as *property;* and many use the *guttural,* which is the *burr* of Northumberland, and the common affectation in Parisian speech, termed *parler gras,* or *grasseyer.*

Table of Articulations.

Labial.	Palatal.	Guttural.		
P	T	K		Mute.
B	D L	G		Simi-mute.
M	N	ng	on	Simi-vowel or nasal.
F	th. S. sh.	ch	H	Aspirate.
V	th. Z. J.	gh		Vocal Aspirate.
pr	R	ghr		Vibratory.

Additional Remarks.

The sound of H does not belong to any of the three positions; and, indeed, is merely a forcible passing of the breath through the back part of the mouth or throat.

CH, in such words as *chain,* means T before SH.

J, as heard in the English name *John*, is a compound sound, *viz.* D before the simple J of the table, which is the S of *vision.*

LL. The liquid or double LL of the French, as heard in the word *paille*, is merely L with the letter Y begun to be pronounced after it. It is heard in the English words *billiard* and *halyard*, and would be their terminating liquid were the syllable *ard* not pronounced.

GN. The soft GN of the Italians and French, is the English N with Y begun to be pronounced after it. It is heard in our word *tanyard;* and in the Italian words *pegnio bagnio;* and in the French word *craignent.*

C, in English, stands always either for S or K, as in the words *certain* and *car*, and has no sound proper to itself.

Q expresses a compound sound, *viz.* of the letter K, with IU following it.

The consonants are best heard by sounding them with voice before them; that is to say, by making them rather terminate a syllable than begin it; pronouncing B, D, G, thus *eb, ed, eg,* rather than their common alphabetical names, *be, de, ge.*

The labial sounds may be made either by the two lips, or by one lip and the opposite teeth. F may be pronounced, for instance, by the lips only, or by the lips and teeth; and some persons awkwardly make it by the under teeth and upper lip.

The letters Y and I, in most modern languages, stand for nearly the same sound. In English, for instance, *bullion* and *minion*, might be written *bulyon* and *minyon*, without suggesting a change of pronounciation. In the words *yard, you, yes,* &c. the Y is a short I, very closely joined to the following syllable. W is also thus a short U, as perceived in the words *war, we,* &c.

The author believes the analysis of articulations to be the best basis for a system of short-hand written characters. He has tried such a system, and has found it exceedingly convenient.

Lisping is chiefly the habitual substitution of the aspirate TH for the S and SH.

Whispering is articulation without voice; that is to say, articulation while breath only is passing.

Stuttering, *stammering*, or *hesitation of speech* are terms implying an interrupted articulation, accompanied generally with more or less of straining and distortion of feature. It is remarkable with respect to this defect, that scientific or regular medicine possesses as yet no cure for it, although the frequent success of non-professional, and often ignorant individuals, by a mode of treatment which they solemnly bind their patients not to divulge, proves the cure to be both possible and not difficult. —The author's attention was drawn to this subject some years ago by an interesting case then submitted to him; and it was in reflecting upon the subject, with a view to treat that case, that he framed the analysis of articulations contained in the preceding pages, and drew up the few observations which are now to follow. A cure was obtained; but as the case possessed a favourable peculiarity in the powerful mind of the individual, and as the author has not had leisure or opportunity since then to pursue the subject, or to ascertain in what respects the plan then tried may agree with that employed by others, he gives his remarks merely as continued elucidation of the subject of speech.

Command over the organs of speech is acquired in the same way, as over all the other muscular organs of the body—as those for walking, skaiting, fencing, performing on musical instruments, &c.;—that is to say, at first, a distinct act of volition is required for every individual movement; but the law of association or habit rendering the actions easier with each successive repetition, they are at last formed into connected tribes or trains, which appear as obedient to a single wish as the separate elements originally were. A child at first exerts as distinct and powerful a volition to pronounce the syllable *pa*, as it does after some practice to double the syllable and make *papa;* or after still more practice, to pronounce the longest and hardest word of its language:—nay, at last, where there is strong and healthy power of association, complete sentences, and even rounded periods of eloquence, are poured out like single words, the mind of the speaker seeming at liberty, after each sentence or period is begun, to meditate and prepare that which is to follow. The faculties of locomotion and of speech being acquired in infancy and early childhood, persons no more recollect how they gradually came, then how their limbs grew; but the progress described above, may be watched by any individual of mature years in his own person, while he is learning to play on a musical instrument. He will find, that at first every finger which is moved to produce a note, obeys a distinct thought and volition; that soon short trains of connected notes become obedient to the will almost like a single note; that by degrees, longer and longer trains or passages become familiar, until at last the instrument is as obedient to the practised player, as voice to the singer, or speech to the orator;—and any sweet modulation may flow on, under the guidance almost solely of sensation and association.

There is great original diversity among individuals as to their powers of association, and therefore, also, as to their aptitude for acquiring the various muscular faculties. Thus some children walk well before a year, others require a much longer time, and some never succeed perfectly until they have had lessons of the dancing master or drill serjeant.—So, again, many people, by ear and imitation alone, learn easily to play on musical instruments; but others must begin by studying the written notes, and the precise *fingering* by which each note is produced on the instrument; and many, unless the notes be constantly before them, cannot play at all.—So again, all persons may be said to learn to speak at first by ear and imitation; but many grow up to a certain age with defects; which judicious lessons from parents or other tutors are required to remove; and there are some, as stutterers, who from a naturally weak or irregular association, retain defects which no ordinary teaching can correct. It appears, then, that an analysis and scale of articulate sounds, with minute description of the organic actions required to produce them, like the scale which we possess for music, in the *gamut* and rules for fingering, should give nearly the same assistance to the speaker, which the gamut gives to the player. Now the table and analysis contained in the preceding pages is intended to supply this information. It is constructed from minute consideration of the organs of speech while in action. It agrees in many respects with the common grammatical divisions of elementary sounds, but in others it pursues the analysis in a different way, and considerably farther. A person who understands it well, will have, while he speaks, an intelligent perception of what he is doing, in addition to the parrot-like faculty of habit or of repeating by rote, and will thus command any desired sound by two powers instead of one. And as a musician, when his musical memory fails him, finds help by thinking of his written notes and their relation to his instrument, so may a stutterer, when hesitating at any sound, receive benefit by thinking of the letter which represents it, and of the position of the organs required for that letter. Then by frequent practice in making the particular combinations of sound which are difficult to him, he may strengthen the useful habit, and ultimately overcome his defect.—Stuttering, in some cases, is relievable at once, by a determination to avoid the usual hurried repetition of the same syllable, by opening the mouth and allowing simple sound to pass, whenever any one oral position threatens to become spasmodically permanent. Should it ever arise from the attempt being made to speak while drawing air into the chest, it may then be avoided by filling the chest well before beginning to speak.

The study of the table of articulations leads to the immediate correction of many minor defects in utterance, and is calculated to facilitate the acquirement of foreign languages. A lisping person, for instance, is cured at once, by being told that the tongue must not touch the teeth in pronouncing the letter S; and a Frenchman who deems it impossible for him to pronounce the English sound of TH, discovers that he cannot avoid doing so if he rests his tongue softly against his teeth, when opened a little, and then forces breath or sound to pass between the tongue and teeth.

Several of the modern languages of Europe consist of nearly the same elementary or radical words, and differ among themselves chiefly by the prevalence in each of certain terminations, and of one or other of the related and convertible sounds classified in the analysis given above. A student, therefore, who by analytical investigation, or considerable practice, has become impressed with the peculiar genius of a language, may invent, or determine by analogy, even before minute study, the majority of those words belonging to each which have sprung from a common origin. This remark is so true with respect to the languages of Italy, Spain, Portugal, and even France, that to persons familiar with them, they are at last listened to rather as the same language spoken by different individuals, than as languages in themselves different.

Ventriloquism is the name commonly given to the art by which an individual can assume characters of voice and speech which are not natural to him, and thus, alone, can imitate closely a conversation held between two or more persons.

The most remarkable diversity is obtained by speaking during inspiration, instead of, as usual, during expiration. The voice so produced is more feeble than ordinary voice, and when accompanied by other circumstances favouring the illusion, it may suggest very completely the idea of a boy calling from the bottom of a pit, or from the interior of a chimney, &c. An unsuspecting peasant is easily tricked into unloading his hay-wagon, to extricate a poor child whom a ventriloquist makes him believe to be packed under the heap, and ready to be smothered there.

A person, by a litttle practice, may acquire the power of producing, without the slightest apparent motion of the lips or countenance, all the articulations except the labial, and of them the F, V, and M, may be tolerably imitated by parts behind; hence by avoiding words in which P and B occur, it is possible to speak without visible movement of the organs, and by assuming the attitude of a listener, to make the deception of ventriloquism complete. The idea which some authors have had (*see Good's Study of Medicines, &c.*,) that the articulations of the ventriloquist are not produced by the tongue and mouth, as in common speech, is altogether an error. The art, carried to a certain degree, is not very difficult, any as person may ascertain who tries it after considering minutely the nature of common speech.

There are also striking varieties of voice producible by speaking with a more acute or grave pitch than usual, and with different degrees of contraction of the mouth; but these may be more properly called *imitations* than *ventriloquism*.

The variety of effect in sound which the human organs are capable of producing is truly surprising. There are adepts in the art of imitations, who not only mimic the speech of all ages and conditions of the human race, but the songs of birds, the cries of animals, and even the sounds produced among inanimate things. Many of these performances become in the highest degree ludicrous, and furnish favourite amusements in our theatres. A Mr. Henderson, of London, about the end of the eighteenth century, used to *kill his calf*, as he called it, to crowded houses every night. After dropping a screen between him and the audience, he caused to issue from behind it all the sounds, even to the minutest particular, which may be heard while a calf is falling a victim in the slaughter-house;—the conversation of the butchers, the struggling and bellowing, and quick breathing of the frightened animal, the whetting of the knife, the plunge, the gush, the agony;—and, disgusting as the idea is in itself, the imitation was so true to nature, that thousands eagerly went to witness the art of the mimic.

The following cases of inanimate sound may be closely imitated by the mouth—the working of a grindstone, including the rush of the water into which it dips, the rough attrition of the steel upon it, and the various changes occurring with change of the pressure;—the working of a saw cutting wood;—the uncorking of a bottle, and the guggling noise of decanting its contents;—the sound of air rushing into a room by a crevice or keyhole in a winter night,—and many others.

It has already been explained, that voice depends on the vibration of the two edges or lips of the slit-like opening of the glottis, by which the air passes to and from the chest. The number of vibrations in a given time, or the pitch of voice, depends, of course, on the length and tension of these edges.

The length is varied by the positions of the arytenoid cartilages, and the tension by the action of small muscles which act on these; and the cavity of the mouth is enlarged or lessened to accord with the number of vibrations, by the rising or falling of the tongue and larynx which form its bottom. The peculiarities of individual voices must depend chiefly on the size and firmness of the cartilaginous box of the larynx, the strength of the muscles of the chest which force the air through the glottis, and the pliancy of the moving parts.

The glottis is smaller in women than in men, and hence their pitch of voice is higher:—with reference to music, the difference is generally of an octave or eight notes.

The voice of a boy, in regard to pitch, is generally the same as that of a woman; but at the age of puberty, the sounding organs in the male enlarge suddenly, and render the voice stronger than before, and by nearly an octave graver. The voice of a eunuch is the voice of the boy continued, because the change called puberty does not take place in him.

Complete loss of voice, for longer or shorter periods, is often experienced by persons while in feeble states of health. The vibrating, and therefore sounding edges of the glottis, which are usually kept tense by the operation of certain muscles, on these ceasing to act, owing to the state of their nerves, will not vibrate as required, and the voice is lost. Slight colds suffice in many people to produce this effect: in others of morbidly sensitive or delicate nervous temperament, it follows fatigue, or any other cause of debility.—Articulation is not destroyed by loss of voice; and whispering answers passably the end of vocal speech.

No intelligent mind can meditate on human speech, and its influence in the world, without being roused to vivid admiration. But for speech, the most gifted individuals who have lived, had they existed at all, could have been little superior in their wordly state to the leading oxen of our heards, or to leading monkeys in the woods. As regarded the rest of mankind, Homer and Newton would have lived in vain. At the present day, among the natives of Australasia, where language may be said scarcely yet to exist, human nature is seen thus brutishly debased; while on the other hand, in the history of the world, we may trace, as a consequence of more perfect speech, all the progress which has been made in art and civilization. "By language (as observed in our preface,) fathers have communicated their gathered experience and reflections to their children; who again transmitted them, with gradual accumulation, to new descendants; and when in the course of ages the precious store had increased, until the simple powers of memory could retain no more, the art of writing arose, making language visible and permanent and enlarging without limit the recepticles of wisdom; and then the art of printing came, which now rolls the still swelling flood of knowledge into every hamlet and hut. Language thus, at the present moment of the world's existence, may be said to bind the whole human race of uncounted millions into one gigantic rational being, whose memory reaches to the beginnings of written record, and retains imperishably the important events that have occurred; whose judgment, analysing the treasures of memory, has already discovered many of the sublime and unchanging laws of nature, and has built on them the arts of life, and through them piercing far into futurity, sees distinctly many events that are to come; and whose eyes, and ears, and observant mind, at this moment in every corner of the earth, are watching and recording new phenomena, for the purpose of still better comprehending the magnificence, and simplicity, and beauty of creation."

THE DIGESTION.

The doctrines of fluidity, illustrating and illustrated by certain phenomena of digestion.

The animal body may be seen at first, in the maternal ovary as a single speck of mucus; but from possessing life—wonderful life—the little nucleus soon gathers to itself substance from around, and increases in bulk. In the beginning it remains attached to the body of its parent, and draws the material of its increase from its parent's blood; but after a certain time it is from the liver and pancreas. After this mixture, a chemical decomposition and separation of parts takes place, and the pure nutriment of the body appears as a milky fluid floating among refuse. This milky fluid, called *chyle*, is taken up all along the canal by the numberless absorbent mouths of the vessels called *lacteals*, and is then carried to the *thoracic duct*, and by it into the blood, to supply the waste. The intestinal canal is about six times as long as the body, affording therefore a very extensive surface from which absorption may take place. That remnant of the chyme which the absorbents refuse, continues its journey onwards, and is discharged.

Much of the process which we have now described is *mechanical*, as will appear immediately; other parts of it are *chemical*, such as the solution of the food by the gastric juice, the separation of the milky chyle, &c.; and parts are *vital*, such as the afflux, just when wanted, of saliva, gastric juice, bile, &c., and the muscular and absorbent actions. He who neglects any one of these three classes of particulars, must have a very incomplete acquaintance with the function.—We proceed now to explain the mechanical or physical circumstances connected with digestion.

The abdomen may be considered as a vessel full of liquid, in which therefore there is pressure in all directions, increasing with the depth (see hydrostatics,) and increased also by the action of the surrounding muscles which form the sides of the cavity.

The justness of this view of the abdomen becomes evident, when we consider that only moistened or semifluid food descends into the stomach, that drink follows, and that gastric and other juices are poured out to mix with the food as it passes on to occupy the long intestinal canal; and then that the intestines externally are perfectly smooth, and moistened by the constant secretion of a lubricating serum, so that they slide among each other, without sensible impediment from friction. The abdomen, therefore, is in fact a roundish smooth vessel filled with a thick fluid, which is farther contained in a perfectly pliant and smooth-coated tube.

Thus the contents of the stomach and bowels, in a living man, are supported like water in surrounding water, and therefore, if the whole contents be of equal specific gravity, no part can descend or advance by its weight. Neither can any general pressure, or contraction of the surrounding parietes, hasten, except at the moment of expulsion, the motion of any contained matter—as has, however, often been supposed; nor can it help to empty one part into another—the stomach, for instance, or the gall bladder, into the small intestine.

For the same reason, however, the very slightest contractile action of any containing part is sufficient to dislodge its contents—gravity as a resistance being neutralized by the surrounding fluid. And when the gall-bladder, or stomach, or any part of the intestinal tube, becomes so full, as to put the elasticity of the coats ever so little upon the stretch, that circumstance alone, unless some muscular action oppose, will cause a discharge of the contents.—The natural action of the intestinal canal is a successive contraction of its circular fibres from above downwards, propelling the contents, just as if a small ring or tube were put round the canal and pushed forwards.

These considerations make evident the common error of supposing, that vomiting can, by the sudden compression of the abdominal viscera, *mechanically* emulge or clear the obstructed biliary ducts. If general pressure of the abdomen could produce this and similar effects, a descent in the diving-bell should be a powerful remedy in human maladies; for nearly fifteen pounds on the inch is added to the ordinary abdominal pressure, at a depth of thirty feet in water.

We hence see also the kind of error into which our predecessors fell so generally, when they attributed much of the digestive power of the stomach to its simple pressure upon the food. The idea probably arose from the contemplation of the stomach or gizzard of a fowl, which is a powerful gristly substance, answering the purpose almost of a mouth and teeth, as well as of a stomach.

It is an error also to suppose that quicksilver, which is sometimes swallowed to remove obstruction, runs through the bowels simply by its weight. On first entering the loose small intestine, it must drag the part containing it to the bottom of the abdomen, and there, the whole intestine must pass, nearly as a rope passes through a ring fixed to the floor. When the mercury arrives at the part of the intestine called the *cæcum*, where the farther course lies upward along the fixed arch of the colon, it probably can be dislodged only by the patient's lying down. Any useful operation of quicksilver, in such cases, may be from its stimulating the bowels, by dragging or displacing them, in the manner above described.

When the abdominal muscles, which are the containing sides of the cavity, become tense, whether from unusual fulness of the cavity, or from their own action, as in any of the straining exertions, a variety of important mechanical effects ensue. Thus,

A full stomach produces—tension and projection of the belly—projection of the diaphragm into the chest, causing hurried breathing, and impeding speech and singing—expulsion of blood from the abdominal vessels, and therefore, congestions elsewhere, as in the arteries of the head, sometimes producing apoplexy.

Abdominal fulness, as in ***dropsy***, ***tympanitis***, ***corpulency***, ***pregnancy***, &c. produces most of the effects now mentioned, in an aggravated degree. If dropsy be allowed to proceed too far without tapping, the patient will die of suffocation from the rise of the diaphragm.—The external veins of the legs and abdomen of a dropsical person are generally turgid, because the blood is pressed into them out of the abdominal cavity, and because the passage of blood through the abdomen is impeded. In tympanitis, or windy dropsy, the viscera hang down in the abdominal cavity, while the air occupies the upper part. In common dropsy, the viscera float about and are supported.

Straining or strong action of the abdominal muscles, and therefore pressure on the abdominal contents, occur with almost

every bodily exertion; for the abdominal mu
tagonists of the great muscles on the back and
and must always come into play with them,
and rigidity to the trunk of the body. This
markably in the actions of lifting, running, wr
the abdominal muscles cannot act in a continued
ly, unless the ribs, from which they arise, beco
during exertion the ribs are supported by the
cles, and by the air in the chest, confined fo
closure of the air-passages in the throat: hence
compression in the chest also when the abdome
and the blood is squeezed towards the extren
cavities at once.—It is important to remark al
are called the strong actions of the chest, as *coug*
blowing, &c., the abdominal muscles are the gr
pulling down the ribs to which they are attach
the chest, and by compressing the abdominal cc
raising up the diaphragm, they shorten the che

The following cases exemplify the effects of
lifting of a great weight, or making any great
the blood up to the head; as is marked by the s
the face.—Coughing will cause closed leech-bite
and sometimes will overcome the action of the
bladder or rectum; it will also produce vomitin
empty the bladder, rectum, or womb, or the eff
will cause the rupture of a blood-vessel in the w
with consequent effusion of blood there. Apo
pens under the same circumstances, from the
vessel in the brain. The rupture of a varic
aneurism, generally happens during exertion.—
ertion, the protrusion is likely to occur at any
abdominal cavity, of some portion of its cont
what is called *hernia* or *rupture*.

Vomiting is produced, not by the forcible cc
stomach, as was long supposed, but chiefly by t
abdominal muscles.—This is proved by the fact
has been removed from a living animal, and a

containing liquid has been substituted for it, and connected with the gullet above and the intestine below; on then injecting an emetic drug into the veins of the animal, vomiting has taken place, as if the stomach had been there and unhurt.* From this we see why, to prevent regurgitation of the food, during exertion, the upper orifice of the stomach requires to be almost as strongly closed, as the sphincters below.

A small pump—in this application called the *stomach-pump*—has lately been introduced into practice, for removing poisons from the stomach in cases where the action of vomiting cannot be excited. It has already saved many lives. It resembles the common small syringe, except that there are two apertures near the end, instead of one, which, owing to valves in them, opening different ways, become what are called a *sucking* and a *forcing* passage. When the object is to extract from the stomach, the pump is worked while its sucking orifice is in connexion with an elastic tube passed into the stomach, and the discharged matter escapes by the *forcing* orifice. When it is desired, on the contrary, to throw cleansing water or other liquid into the stomach, the connexion of the apertures and the tubes is reversed.

As a pump may not be always procurable when the occasion for it arises, the profession should be aware, that a simple tube will, in many cases, answer the purpose as well, if not better. If the tube be introduced, and the body of the patient be so placed that the tube forms a downward channel from the stomach, all fluid matter will escape from the stomach by it, as water escapes from a funnel by its pipe; and if the outer end of the tube be kept immersed in liquid, there will be during the discharge a syphon-action of considerable force. On changing the posture of the body, water may be poured in through the same tube to wash the stomach. Such a tube, made long enough, might, if desired, be rendered a complete bent syphon, the necessary preliminary suction having to be made by a syringe, or by the mouth through an intervening vessel.

---

* It must not be supposed however that the stomach is always inactive in the effort of vomiting; vomiting is the *joint effect* of the contraction of the stomach, and of the abdominal muscles. AM. ED.

But there is a still easier mode than either of these now described, of dislodging poison from a torpid stomach, *viz.* merely to place the patient so that the mouth shall be considerably lower than the stomach,—as with the body lying across a chair or on a sofa, and the face brought near the floor,—and then if necessary, to press on the stomach with the hand. The cardiac orifice opens readily in such a case, and the stomach is emptied like any other inverted vessel.*

Useful as the pump may prove, upon occasions, in evacuating the stomach, its more ancient office of injecting the enema is still the most important—and recent experience seems to show that such injection may become a remedy of more extensive utility than had yet been suspected. From an erroneous opinion, that what has been called the valve of the cœcum acts as a perfect valve, allowing passage downwards only, few practitioners have ventured to order much liquid to be injected, for fear of overstretching or bursting the lower part of the intestine; and the possibility of thus relieving disease above the supposed valve has scarcely been contemplated. It is now ascertained, however, that fluid may be safely injected, even until it reach the stomach.—Perhaps few, if any cases of obstruction of bowels, could resist the gentle force of penetrating water, and if so, a mechanical remedy of certain effect may, in many cases, be substituted for the drastic purgatives and pernicious bleedings now used, and often used in vain.—From what has been said above of the abdomen and the intestinal canal, it appears that an injection tends to spread itself with singular uniformity over the whole. This tendency may be rendered obvious to sight, by throwing a sheep's intestine recently extracted, into a bucket of water, and then pumping water in at one end:—a stream will issue strongly at the other end, although several feet distant almost immediately, and without any intermediate part having become sensibly tense.—Of course, in the living body, in cases of spasm or obstruction, the liquid must be thrown in against resistance very gradually.

---

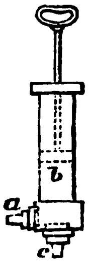
* In his enthusiasm for explaining all things by physical laws, the author forgets that he is treating of *living* organs. Only a few paragraphs back, he informs us that the upper orifice of the stomach is almost as strongly closed, as the sphincters below, and yet he tells us that by inverting a man and pressing on his stomach, the orifice will be readily opened and this organ emptied, like any other inverted vessel. This will not be found so easy in practice as is represented. It is possible however, that in some individuals, the giddiness produced by the dependent position of the head, recommended, aided by strong pressure on the stomach may cause nausea, and even excite *actual vomiting;* but this will not be the mechanical emptying the stomach alluded to by our author. AM. ED.

That case is called *introsusception* of the bowel, in which an upper portion falls, or is received into a portion below, and the receiving part, mistaking the received for descending food, holds it fast. This occurrence forms a complete obstruction, and generally proves fatal. Many infants, with irritable bowels, die of it.—Now a copious enema, such as we have described above, is almost a certain cure. The liquid advances until it reaches the part where the portion of gut has been swallowed by gut below; and as it cannot pass without pushing the introsuscepted portion back to liberty, it effects the cure.*

The *perpetual syringe*, or *little valved pump*, lately used in applications to the animal body, can inject or withdraw any quantity, and is therefore very superior, for almost every purpose, to the old large syringes which had no valves, and which, without being removed, could inject only once their fill. With well adapted additional apparatus, the same instrument will answer for throwing up the enema, clearing the stomach, transfusing blood, exhausting the cupping-glass, relieving the over-distended breast, the lotio vesicæ et urethræ, &c. No surgical

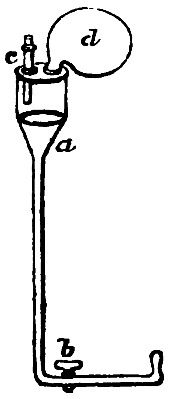
---

* This can only possibly succeed very soon after the introsusception has taken place. After a time inflammation occurs and adhesion takes place between the introsuscepted portion and the portion of the bowel in which it is received.
Am. Ed.



apparatus is now complete without one. The annexed outline represents such a syringe. The aperture *c* is rendered a *sucking orifice*, by a valve at it, opening inwards; and *a* is the forcing orifice, rendered such by a valve opening outwards: *b* is the piston, with its handle. The valves may be variously made, or a single *double-way cock* may be used instead of both. Convenient dimensions for the syringe, are four inches for the length, and three-quarters of an inch for the diameter.

In a case of diseased rectum, where it was necessary to use an enema daily, or oftener, the *enema funnel*, suggested by the author, and represented here, was found more manageable by the patient than any other instrument. If the tube *a b* be about two feet long, the liquid column contained *in* it suffices to overcome the ordinary abdominal resistance; but if a very short tube be used, there must be, instead of an open funnel *a*, a close vessel, as represented here by the dotted line above the funnel, having a bladder of air *d* connected with it, and a bottle-neck and cork, or a cock, at *c*, for admitting the enema. On pouring in the liquid at *c*, the air in the vessel *c a* is forced into the bladder, and on then closing the opening at *c*, and compressing the bladder, it is evident, that any desired degree of injecting pressure may be exerted on the enema. This apparatus is both cheaper and more simple than any syringe, and is equally effectual, and the bladder never being wetted, lasts long: *b* is a cock kept shut until the moment of injection.



By viewing the abdomen in the true light of a vessel or bag filled with liquid which is seeking to escape in all directions, we have the explanation of several circumstances connected with *hernia* or *rupture*; in which accident the containing sides of the abdomen in some part give way, and allow a portion of the viscera to escape, so as to form a tumour under the skin.

Hernia may be produced by all causes which strain or weaken the muscles: as by leaping, lifting great weights, coughing and sneezing, lying with the belly across a bench or yard—as on ship-board, over-distension of belly by eating and drinking, corpulency, dropsy, pregnancy; debility of muscle from dissipation, &c.

The reason that a rupture increases so rapidly after it has once begun is, that the protruding part is truly a fluid wedge, of which, therefore, the opening force increases with the diameter. This shows the singular importance of arresting the accident in its very commencement. The trusses used to repress rupture were described at page 233.

In attempting to return any part of the abdominal contents which may have escaped as a rupture, we should recollect, that a soft uniform pressure of squeezing exerted upon the tumour by the hands of the operator, if greater than the internal pressure of the abdomen, is slowly pushing back again any fluid matter that can ooze inward from the tumour; and by thus gradually lessening its size, may effect the desired object, without the adoption of the last resource of cutting parts to widen the inlet. When, in such a case, an operator sees clearly with the mind's eye what is passing under his hands, his efforts may often be successful, where a less intelligent individual would fail. No man practises medicine long, whatever his nominal department, without having opportunities of saving life, or of preventing a serious operation, by judicious management of recent hernia. The barbarous old fashion of lifting the patient by his heels and shaking him, that the weight of the bowels might drag back again the part which had escaped, was founded on ignorance of the fact, that the weight of the bowels in all positions of the body, is supported almost entirely, not by their attachments, but by the surrounding parts.

The function sketched in the preceding paragraphs, by which the animal body assumes foreign matters from around, and converts them into its own substance, is little inviting in some of its details, but taken altogether is one of the most wonderful subjects which can engage the human attention. It points directly to the curious and yet unanswered question—what is LIFE? The student of nature may analyze with all his art those minute portions of matter called *seeds* and *ova*, which he knows to be the rudiments of future creatures, and the links by which endless generations of living creatures hang to existence: but he cannot disentangle and display apart their mysterious LIFE! that something under the influence of which each little germ in due time swells out, to fill an invisible mould of maturity which determines its forms and proportions. One such substance thus becomes a beautious rose-bush; another a noble oak; a third an eagle, a fourth an elephant—yea, in the same way, out of the rude materials of broken seeds and roots, and leaves of plants, and bits of animal flesh, is built up the human frame itself, whether of the active male, combining gracefulness with strength, or of the gentler woman, with beauty around her as light. How passing strange that such should be the origin of the bright human eye, whose glance pierces as if the invisible soul were shot with it—of the lips which pour forth sweetest eloquence—of the larynx, which by vibrating, fills the surrounding air with music; and more wonderful than all, of that mass shut up within the bony fortress of the scull, whose delicate and curious texture is the abode of the soul, with its reason which contemplates, and its sensibility which delights in these and endless other miracles of creation.

THE

ANALYTICAL TABLE.

INTRODUCTION.
  Progress of man and stationary condition of inferior animals.
  The progress more rapid at present than ever.
  The divisions of human knowledge.
  Natural Philosophy particularly considered.
SYNOPSIS.
  The fundamental truths of natural philosophy explained under the terms *atom*, *attraction*, *repulsion*, and *inertia*—the divisions of this work, 43.

PART I.—THE FUNDAMENTAL TRUTHS minutely examined and used to explain the general constitution of material substances, and of the motions going on among them.
  SECT. I.—CONSTITUTION ON MATERIAL MASSES, 47.
    ATOMS—minute—indestructible—occupying space, 47.
    ATTRACTION of atoms is mutual, 51.
      Gravitation, 54—Cohesion, 54—Capillary attraction, 56—Chemical attraction, 57—Definite proportions, 58.
    REPULSION—The influence of heat on masses, 59.
      Solid—liquid—air, 61.
      Repulsion of surfaces, 63.
      Modifications of Masses:—Crystal, 64—Porosity, 66—Density, 67—Hardness, 69—Elasticity, 70—Brittleness, 71 Malleability, 72—Ductility, 72—Pliancy, 73—Tenacity, 73.
  SECT. II.—MOTIONS AMONG BODIES, 78.
    Motion and Rest:
    INERTIA of matter, 79.
      Motion is naturally permanent, 83—uniform, 86—straight, 88.

Centripetal and centrifugal forces, 89.
Quantity of motion and force—momentum, 93.
Direction of forces and composition of motion, 97.
The two forces of nature are *Attraction* and *Repulsion*, 101.
Accelerated motion, 102.
Retarded motion, 104.
Pendulum and balance wheel, 105.
Bent motion, 111.
Tides, winds, currents, &c. obey *attraction*, 115.
Explosions, steam, &c. obey repulsion, 115.
All great velocities are results of continued action, and are destroyed by continued action, 116.
Action and re-action equal and contrary, 122.

PART II.—DOCTRINES OF SOLIDS, or MECHANICS, 141.
Force moving a part must move the whole or break off the part, 142.
Centres of inertia and gravity, 142.
In inanimate bodies, 145.
In animal bodies, 150—Sea sickness, 153.
Influence on the idea of beauty, &c. 154.
Solids moving round a centre, or so that different parts may have different speed, 157.
Simple machines, 157.
Lever, 164—Wheel and axle, 171—Inclined plane, 175—Wedge, 177—Screw, 178—Pulley, 179—Engine of oblique action, 181.
Fly-wheels, 184.
Complex machines, 187.
Friction, 189.
Wheel carriages, 190—Railways, 194.
Strength of materials, 196.
Influence of form—Arches, &c. 201.
ANIMAL MECHANICS, 207.
Scull, &c. 207.
Spine and its distortions, 209.
Limbs and mechanical surgery, 215.
Living force, 225—Tread-mill, 230.
Surgical instruments, 231.

PART III.—DOCTRINES OF FLUIDS, or HYDRODYNAMICS, 236.

- SECT. I.—HYDROSTATICS, or fluids in repose, 236.
  - Pressure in a fluid extends equally through the whole, 238.
    - Hydrostatic press, &c. 240.
  - Pressure in a fluid increases with the depth, 241.
    - Compressibility of water, &c. 242.
    - Not influenced by shape of vessel, 245.
  - Level surface of fluids, 246.
    - Spirit level, 247—Canals, 248—Running streams, 250, gradual change of the earth's surface produced by running water, 251.
    - Same level in communicating vessels, 257.
      - City water-works, 258.
      - Springs and wells, 260.
    - Support of bodies floating in fluids, 262.
      - Specific gravities, 264.
      - Floating bodies, 270.
      - Swimming of man and inferior animals, 272.
      - Ballast, 276.
      - Fluids of different density, 278.
- SECT. II—PNEUMATICS, or phenomena of air, 282.
  - Lightness, 285.
  - Elasticity, 285.
    - Air-pumps, 286—Diving-bell, 291—Water-balloon, 293—Hero's fountain, 295.
  - Pressure in all directions, 296.
  - Pressure as depth, 296.
    - Weight of the atmosphere, 296.
  - Atmospheric pressure on solids, 299.
    - Magdeburgh hemispheres, 300.
    - Pneumatic tractor, 301.
  - Atmospheric pressure on liquids 303.
    - Pumps, 306—Syphon 307—Intermitting fountains, 308—Bird glass, 310—Vent plugs, 310—Barometer, 314.
  - Atmospheric pressure on animal body, 311.
    - Cupping, &c. 312.
  - Atmospheric pressure determines the liquid or æriform state of certain substances, 322.

- Boiling, 323.
- Boiling at different heights, 324.
- Boiling in vacuo and distilling, 327.
- Elastic force of steam, 329.
  - Steam engines, 331.
  - Explosions, 339.
- Atmospheric pressure affecting combinations of bodies, 340.
  - Effervescence—sparkling liquids, 341.
- Atmospheric pressure affecting the density and temperature of the air, 342.
  - Climate depending on elevation, 343.
- Atmospheric pressure affecting the humidity of the air, 344.
  - Rain, mist, snow, hail, dew, 345.
  - Rain and clouds among mountains, 348.
- Fluid support or floating in air, 350.
  - Balloons, 350.
  - Ascent of flame and smoke, 353.
  - Chimneys, 354.
  - Warming and ventilating houses, 358.
    - Apartments for consumptive patients, 362.
  - Winds, 363.
    - Trade-winds, 363.
    - Land and sea breezes, 365
    - Monsoons, 366.
  - Pneumatic trough, 367.
  - Gasometer, 368.
  - Pneumatic chemistry, 370.
- SECT. III.—HYDRAULICS, or fluids in motion, 371.
  - Fluids moving in channels or issuing from them, 371.
    - Aqueducts, 374.
    - Fountains and jets, 374.
- Waves, 375.
- Momentum and resistance of fluids, 380.
  - Resistance to ships, &c. increases much more rapidly than the velocity, 381.
    - Steam-boats, 381.
    - Paddle-wheels, 382.
  - Resistance to bodies in air, 383.
  - Fluid resistance limits many velocities, 384.

Fluid resistance is influenced by shape of solid, 385.
Water-wheels, 386.
Fluid resistance proportioned to surface of contact, and not to quantity of matter, 387.
Projectiles, 388—levigating, 389—Winnowing—Washing gold-dust, 390.
Oblique action of fluids, 390.
Navigation—Sails, 391—Rudder, 392.
Windmills, 394—Feathered arrows, 395—Paper-kites, 396.
Lifting fluids, 398.
Buckets—Pumps—Wheels—Water-screw, 399—Water-ram, 401.
SECT. IV.—ACOUSTICS, or doctrines of sound, 402.
Nature of simple sound, 403.
Continued sound or tone, 404—Grave, or sharp tones, 407
Musical sounds, 408.
Musical scale, 410.
Melody—Harmony—Accompaniment—Time, 412.
Musical instruments, 413.
Tuning-forks, 413.
Musical ear, 417.
Spreading of sound—in solid and fluid 419—Stethoscope, 422.
Velocity of sound, 423—Many examples.
Reflection of sound, 424.
Echo—Whispering galleries—Ear-trumpets—Speaking-trumpets, 425.
Animal ear, 429.
SECT. V.—ANIMAL HYDROSTATICS AND HYDRAULICS, or Fluidity in relation to animals, 432.
1. Circulation of blood:
In arteries, 436.
In capillaries, 442.
In veins, 446.
Force of the heart, 458.
Velocity of blood, 458.
The pulse, 460.
Circulation in the head, 466.
Effects of position on the circulation, 469.
Fainting from diminished arterial tension, 470.

THE NEW YORK PUBLIC LIBRARY
REFERENCE DEPARTMENT

This book is under no circumstances to be taken from the Building

form 410